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McMullen et al.

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(54) **AXIAL GAP GENERATOR MEASUREMENT TOOL**

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(51) **Int. Cl.**
H02K 11/21 (2016.01)
E21B 43/12 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***E21B 43/128*** (2013.01); ***E21B 4/003*** (2013.01); ***E21B 4/02*** (2013.01); ***E21B 4/04*** (2013.01); ***E21B 17/028*** (2013.01); ***E21B 41/0085*** (2013.01); ***E21B 43/121*** (2013.01); ***E21B 47/0007*** (2013.01); ***E21B 47/01*** (2013.01); ***E21B 47/06*** (2013.01); ***E21B 47/09*** (2013.01); ***E21B 47/12*** (2013.01); ***F04B 17/03*** (2013.01); ***F04B 47/04*** (2013.01); ***F04D 13/026*** (2013.01); ***F04D 13/064*** (2013.01); ***F04D 13/0633*** (2013.01); ***F04D 13/08*** (2013.01); ***F04D 13/086*** (2013.01); ***F04D 13/10*** (2013.01); ***F04D 29/041*** (2013.01); ***F04D 29/048*** (2013.01); ***F04D 29/051*** (2013.01); ***F16C 32/0474*** (2013.01); ***F16C 32/0476*** (2013.01); ***F16C 37/005*** (2013.01); ***H02H 7/005*** (2013.01); ***H02K 1/2793*** (2013.01); ***H02K 3/42*** (2013.01); ***H02K 5/132*** (2013.01); ***H02K 7/09*** (2013.01); ***H02K 7/14*** (2013.01); ***H02K 7/1807*** (2013.01); ***H02K 11/21*** (2016.01); ***H02K 11/27*** (2016.01);
(Continued)

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CPC H02K 5/128; H02K 5/12; H02K 15/03; H02K 1/182; H02K 1/2793; H02K 2201/03; E21B 4/02; E21B 43/128; E21B 43/12; E21B 17/028; F16F 15/03; F16F 15/02
USPC 310/168, 87, 90.5
See application file for complete search history.

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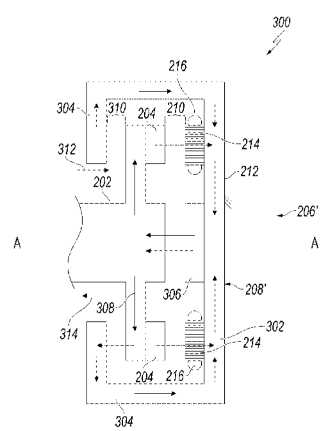
(57) **ABSTRACT**

A tool includes a device including a housing and a rotor, the rotor to rotate about a longitudinal axis, and an axial gap generator including a stator assembly positioned adjacent to the rotor. The axial gap generator generates a voltage signal as a function of a gap spacing between the stator assembly
(Continued)



and the rotor, the gap spacing being parallel to the longitudinal axis.

10 Claims, 19 Drawing Sheets

(51) **Int. Cl.**

E21B 17/02	(2006.01)
E21B 41/00	(2006.01)
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H02K 5/132	(2006.01)
E21B 4/04	(2006.01)
F04D 13/06	(2006.01)
F04D 13/10	(2006.01)
E21B 47/01	(2012.01)
E21B 47/06	(2012.01)
E21B 47/09	(2012.01)
E21B 47/12	(2012.01)
F04D 29/041	(2006.01)
F04D 29/048	(2006.01)
F16C 32/04	(2006.01)
F16C 37/00	(2006.01)
E21B 47/00	(2012.01)
F04B 17/03	(2006.01)
F04B 47/04	(2006.01)
H02K 1/27	(2006.01)
H02K 7/09	(2006.01)
H02K 7/18	(2006.01)
H02K 11/27	(2016.01)
H02K 11/30	(2016.01)
F04D 29/051	(2006.01)
H02H 7/00	(2006.01)
H02K 7/14	(2006.01)
H02P 29/40	(2016.01)
H02K 3/42	(2006.01)
H02K 21/14	(2006.01)
E21B 4/00	(2006.01)
F04D 13/02	(2006.01)
H02K 5/128	(2006.01)
F16F 15/03	(2006.01)
H02K 15/03	(2006.01)
E21B 33/12	(2006.01)
E21B 43/16	(2006.01)

(52) **U.S. Cl.**

CPC ***H02K 11/30*** (2016.01); ***H02K 21/14*** (2013.01); ***H02P 29/40*** (2016.02); *E21B 33/12* (2013.01); *E21B 43/168* (2013.01); *E21B 47/065* (2013.01); *F16C 32/044* (2013.01); *F16C 2380/26* (2013.01); *F16F 15/03* (2013.01); *H02K 5/128* (2013.01); *H02K 15/03* (2013.01); *H02K 2205/03* (2013.01)

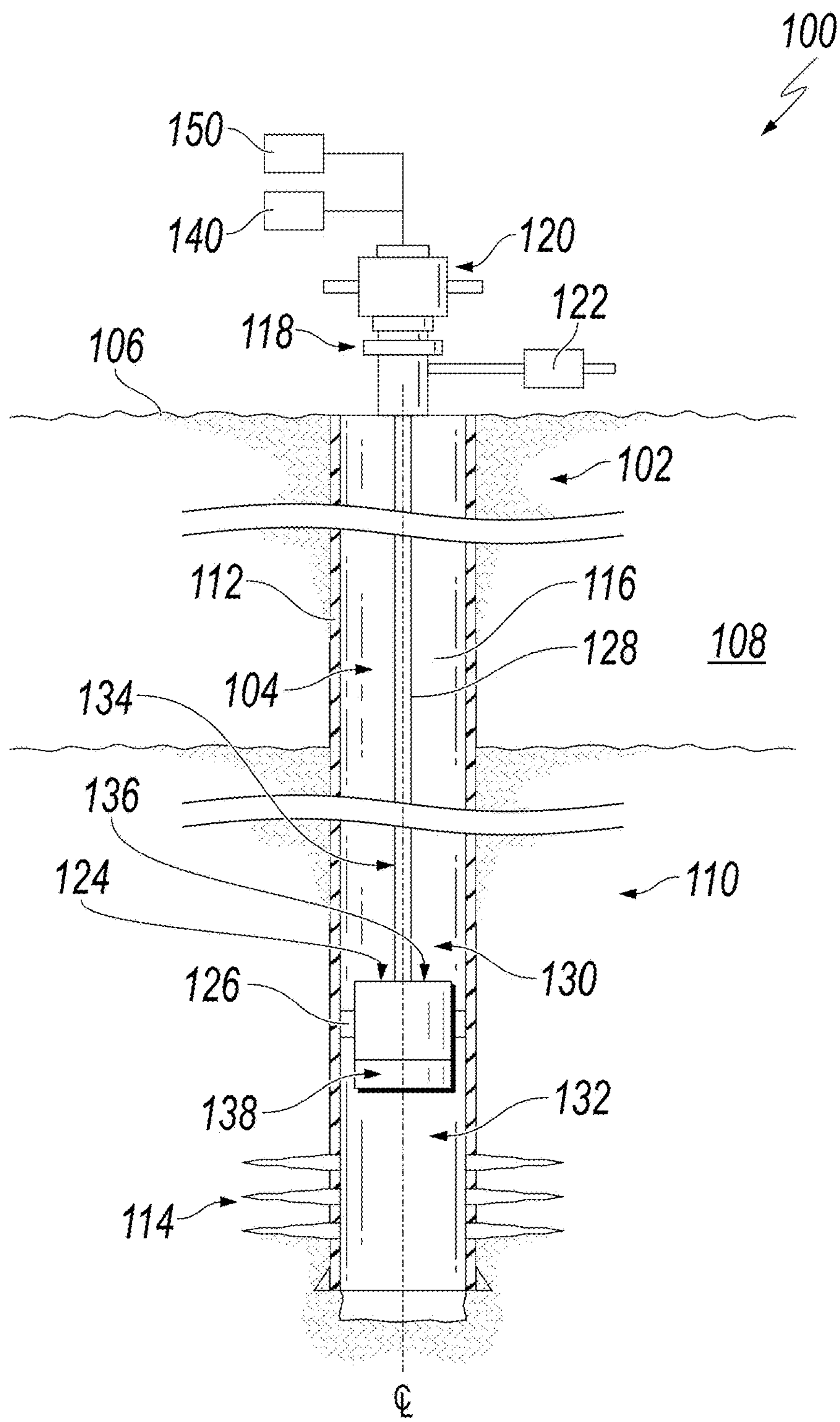
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FIG. 1

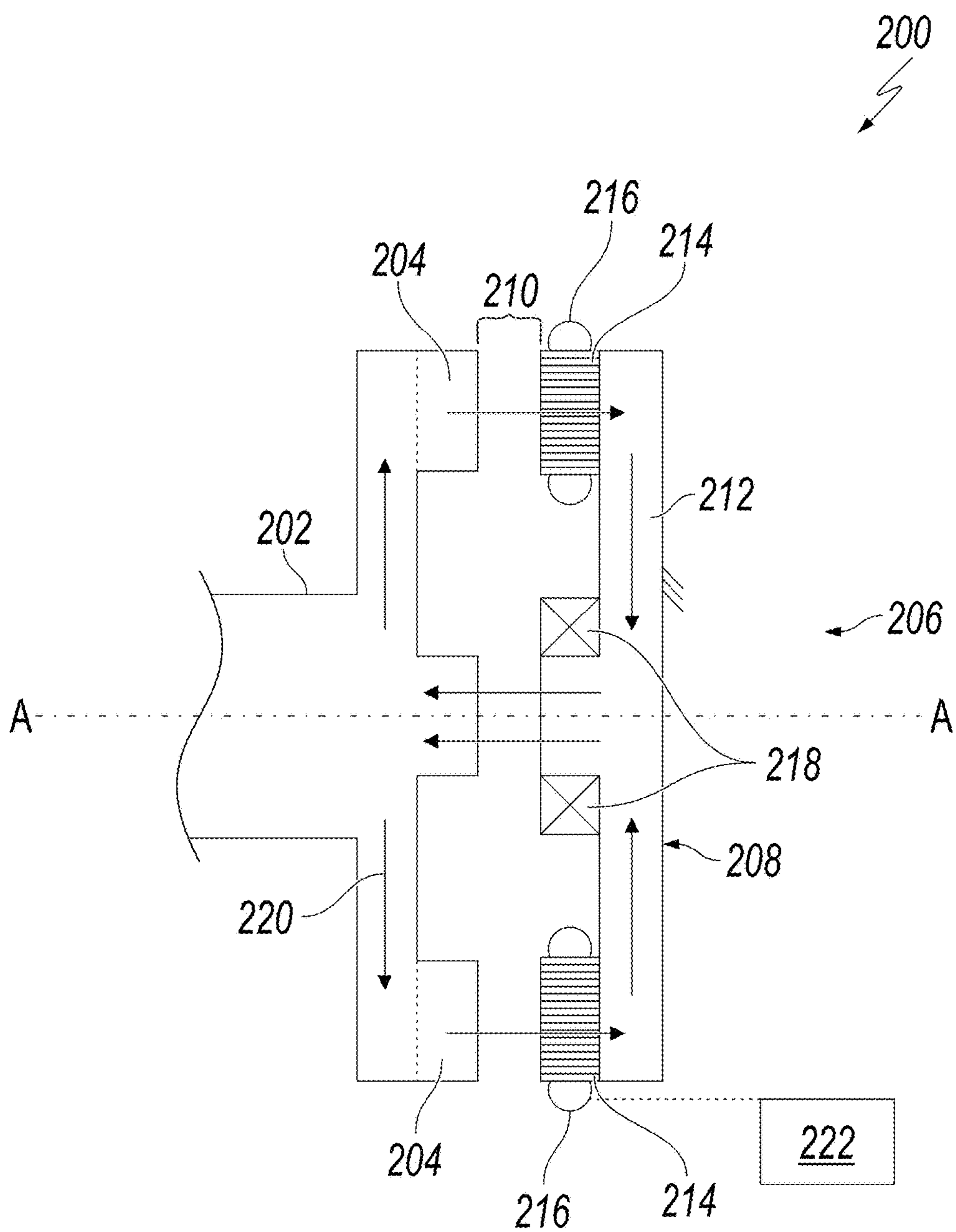


FIG. 2A

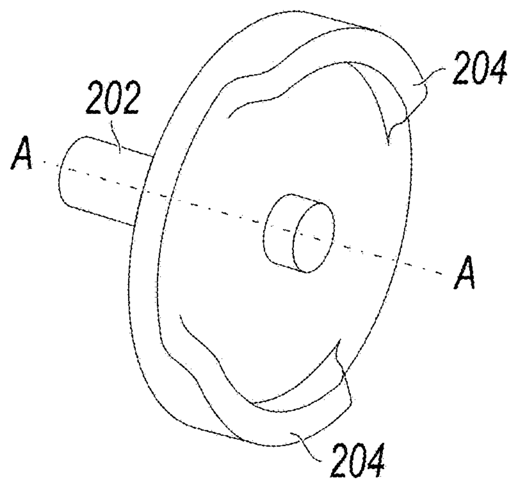


FIG. 2B

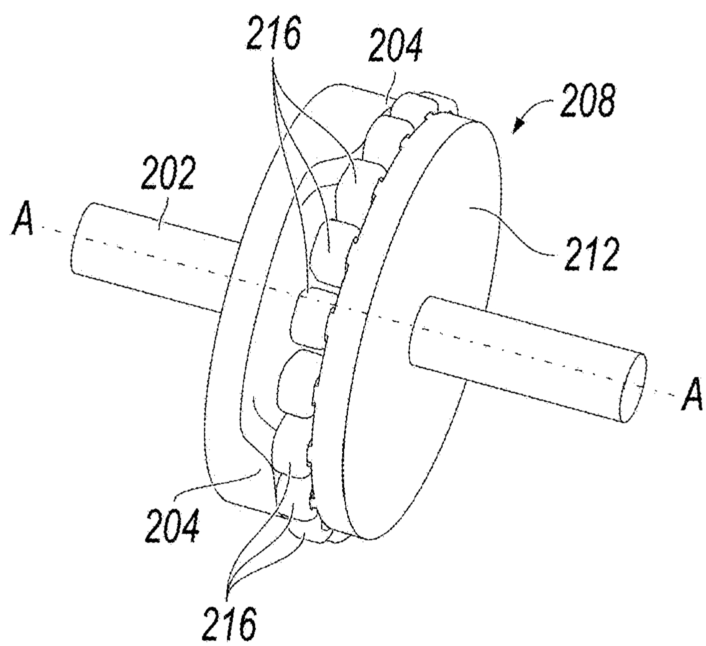
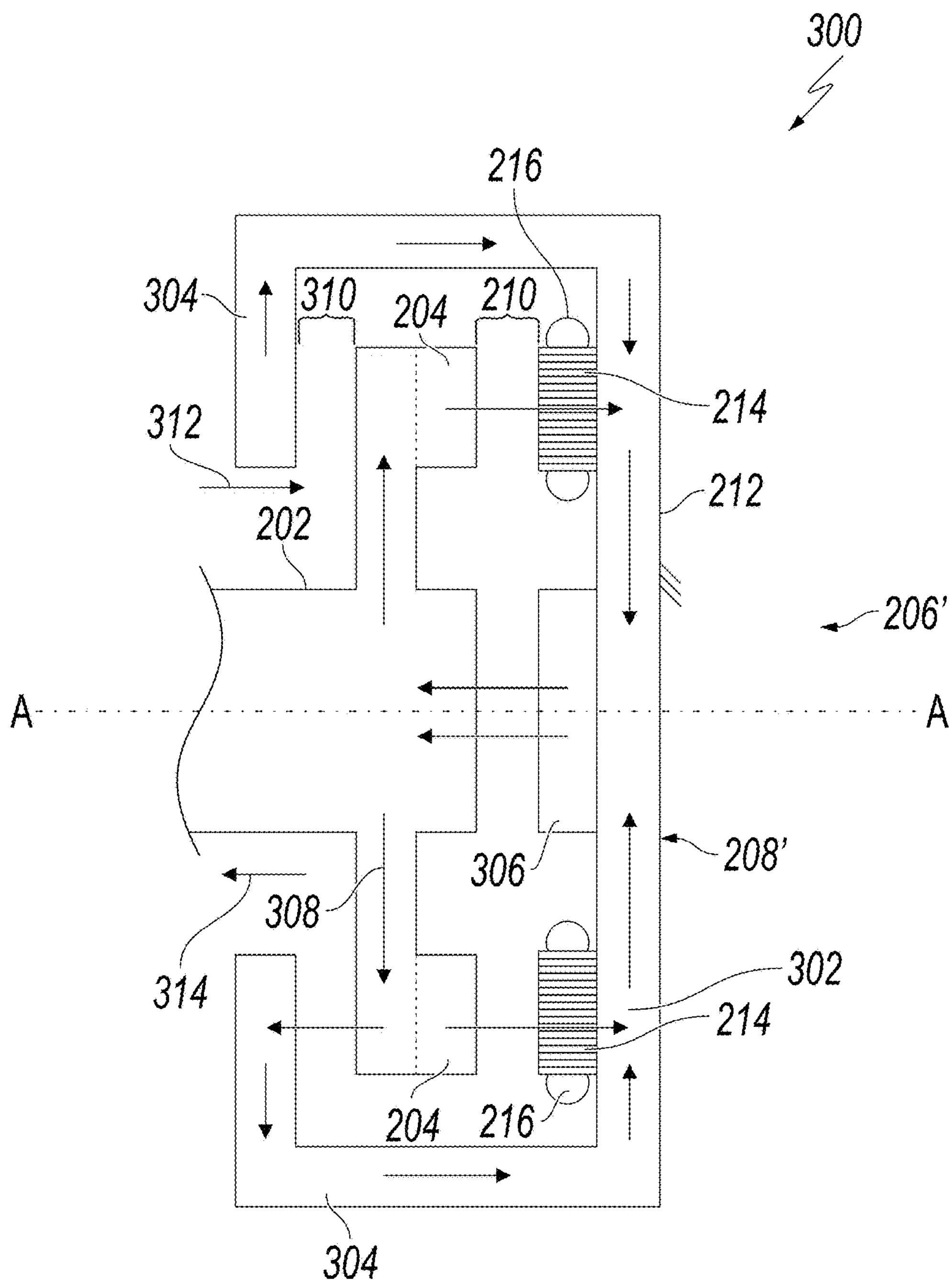


FIG. 2C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216
304
310
204
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214
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212
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206'
A
A
208'
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314
302
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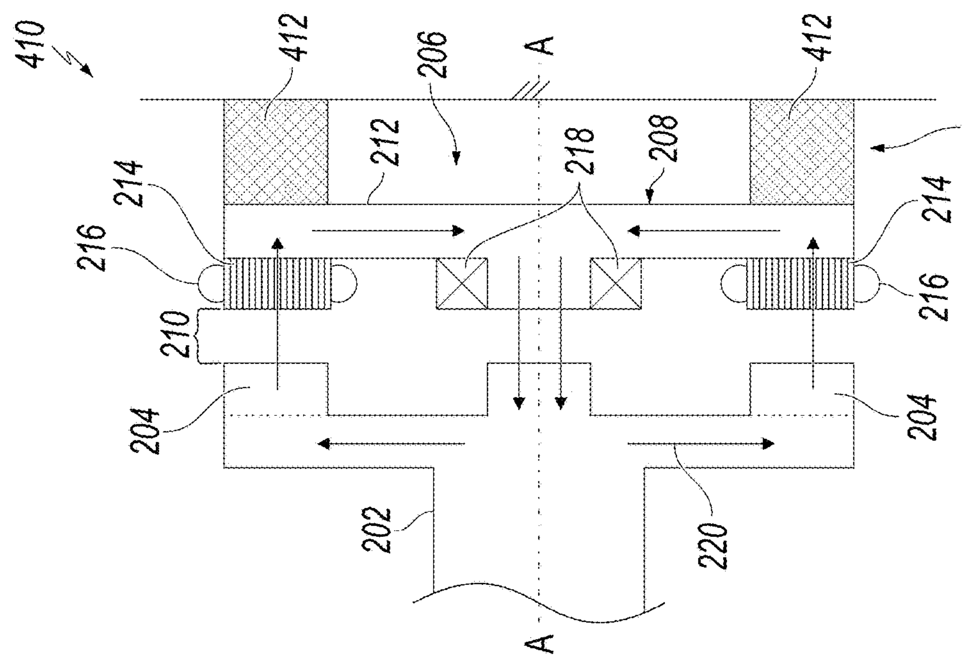
204
216
304

FIG. 3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212
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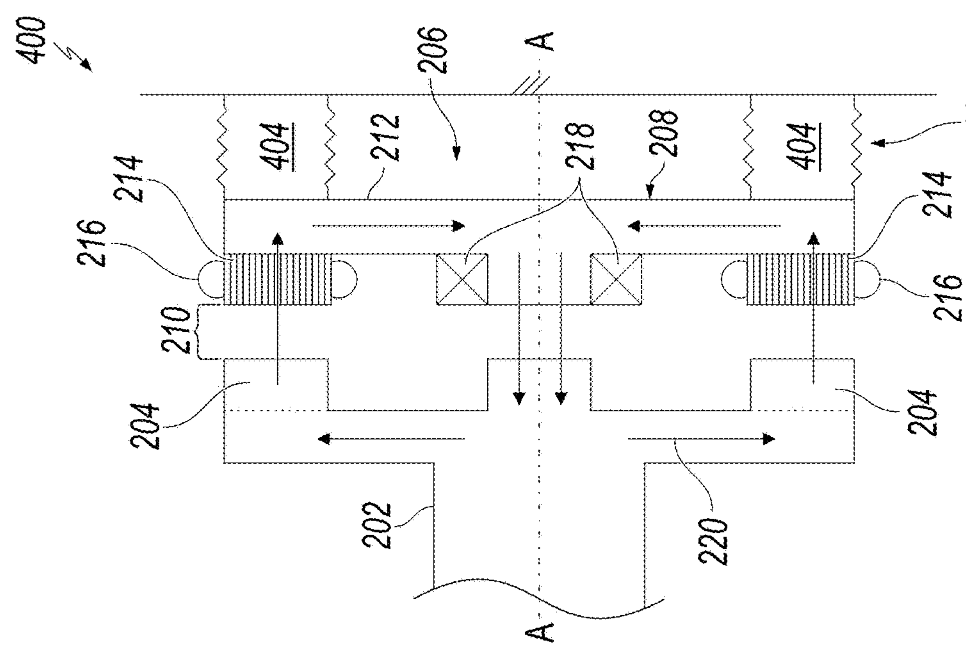
202
220

FIG. 4B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A
212
208
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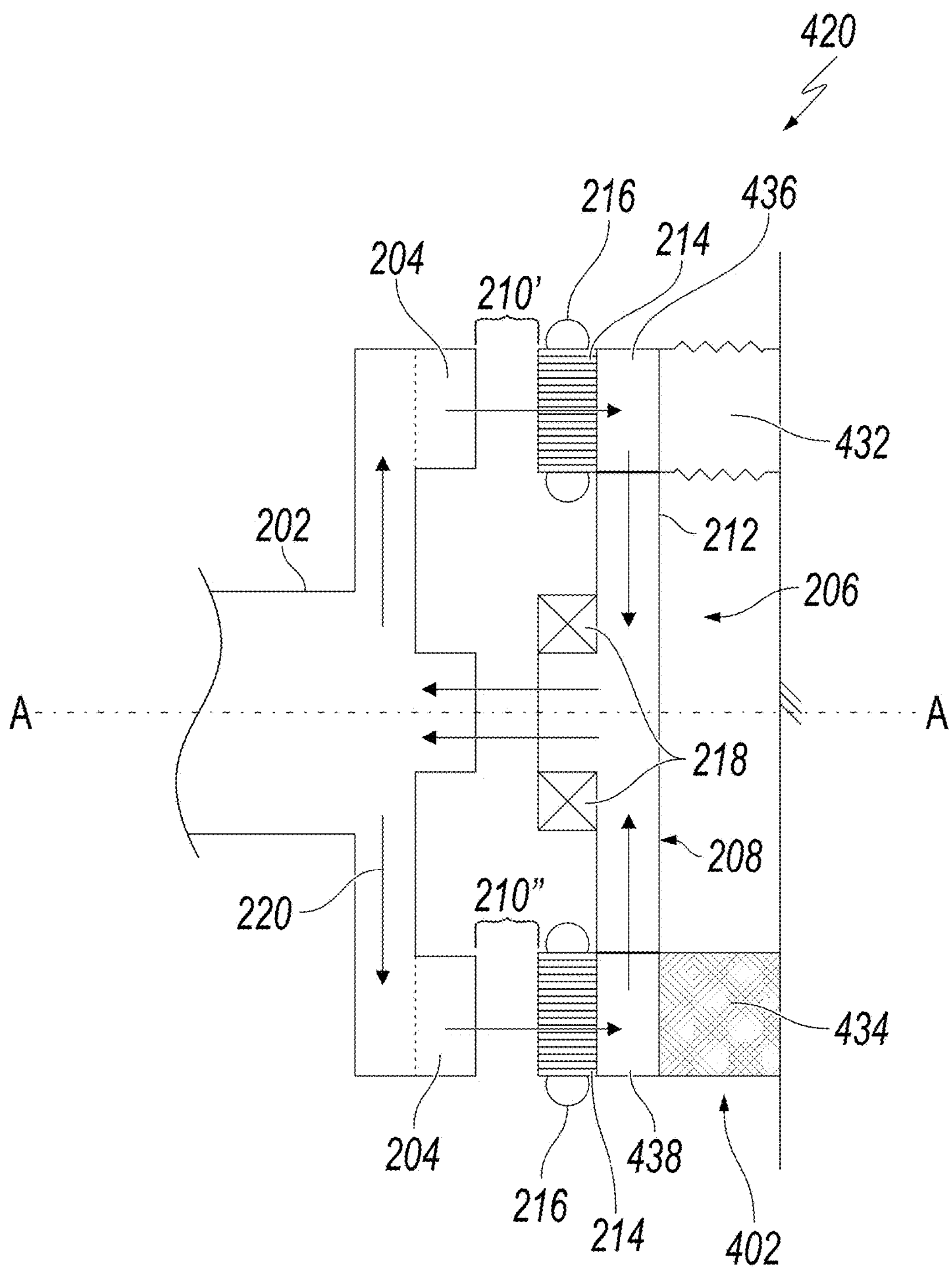
FIG. 4A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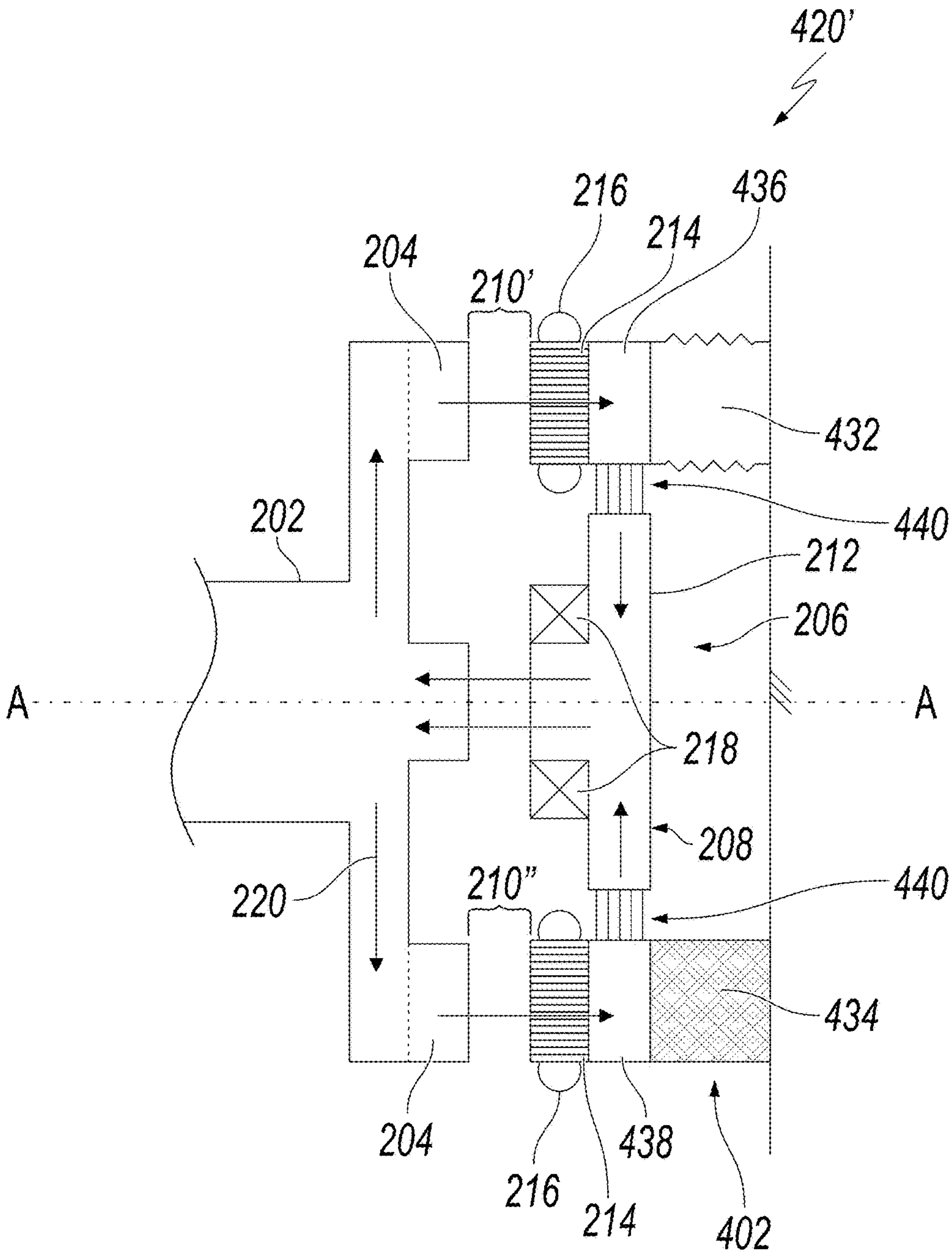
216
436
214
204
210'
432
202
212
206
A
A
218
208
220
210"
434
204
438
216
214
402

FIG. 4C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214
204
210'
432
440
202
212
206
A
A
218
208
220
210"
440
434
204
216
214
438
402

FIG. 4D

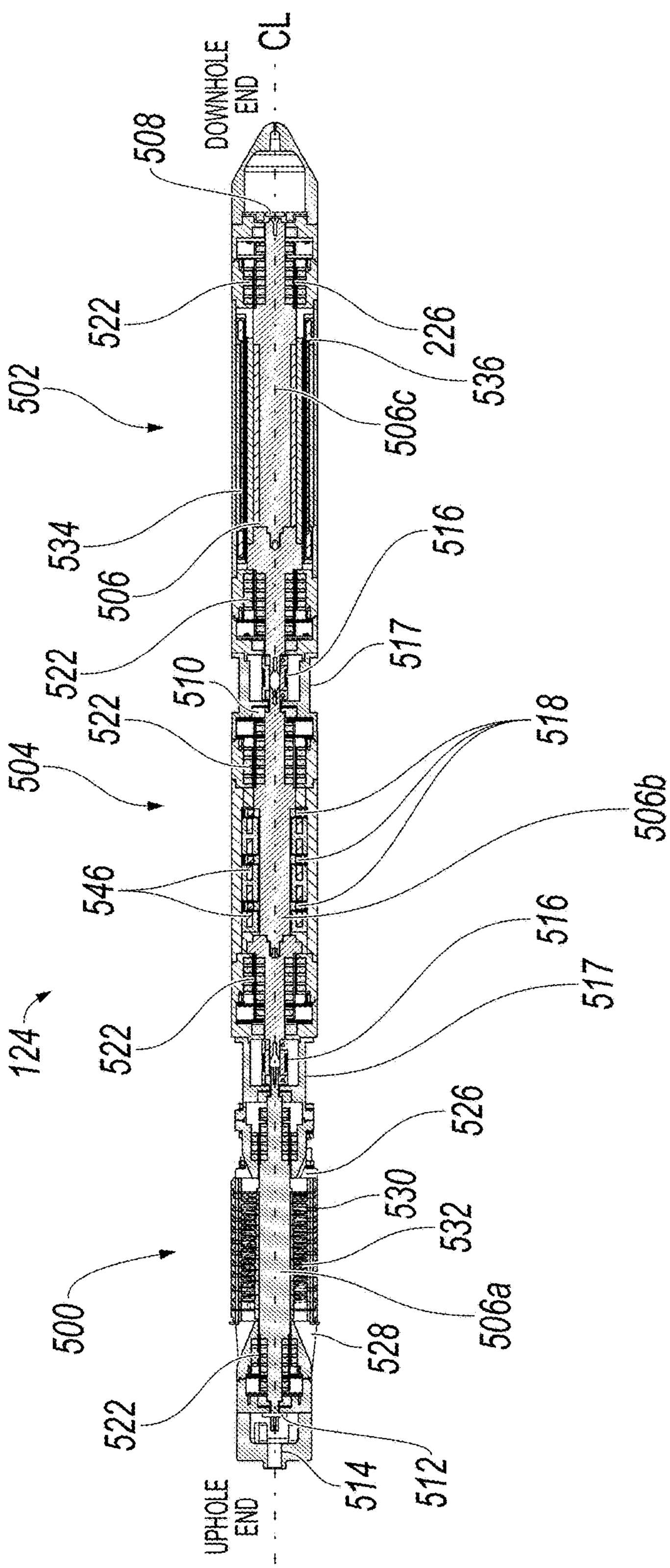

DOWNHOLE END
CL
508
522
226
536
502
506c
534
506
516
517
522
510
522
504
518
506b
546
516
517
124
522
526
530
532
500
506a
528
522
512
514
UPHOLE END

FIG. 5

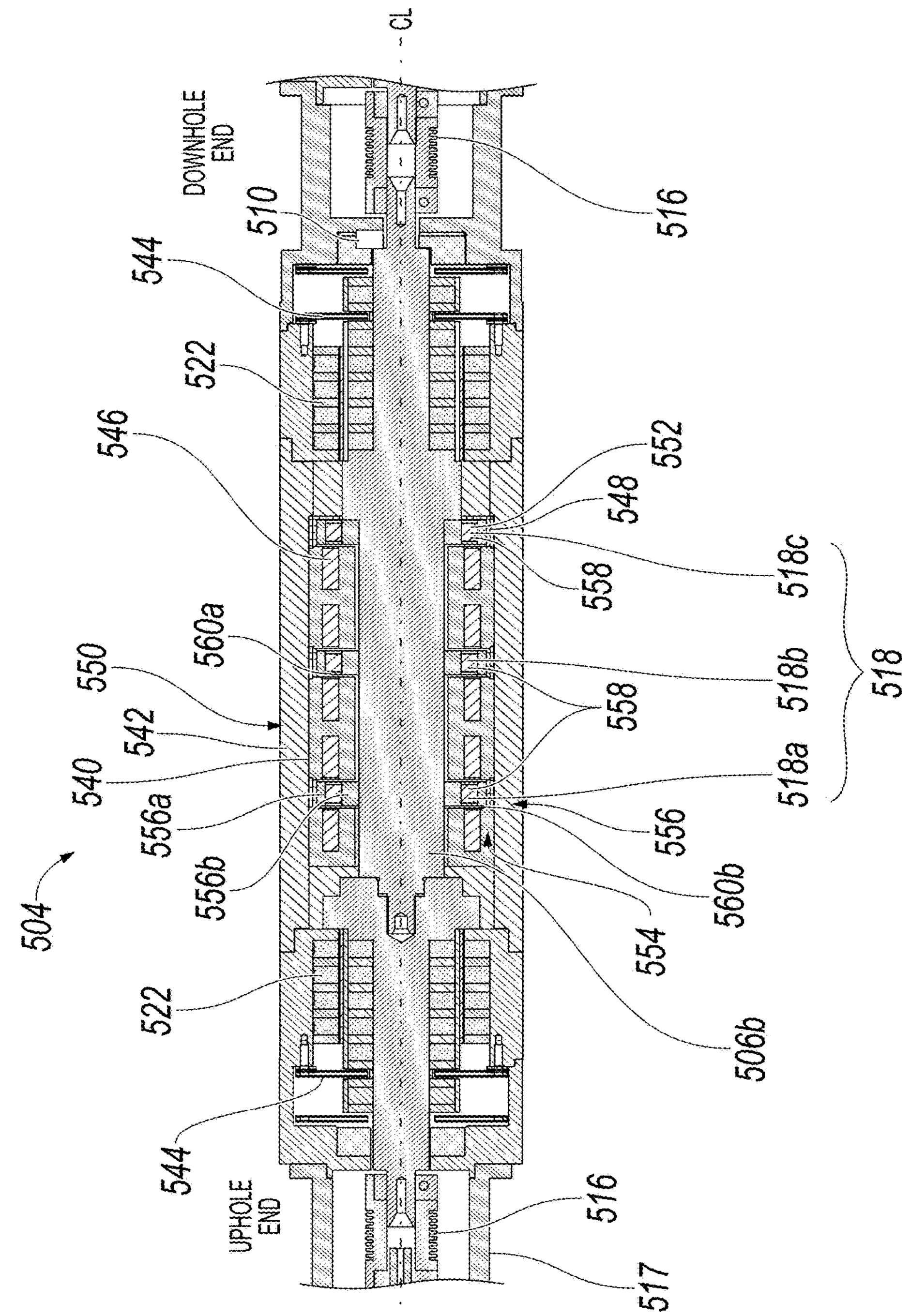

CL
DOWNHOLE END
510
516
544
522
546
552
548
558
518c
560a
550
542
540
556a
556b
504
518b
518
518a
556
560b
554
506b
522
544
UPHOLE END
516
517

FIG. 6A

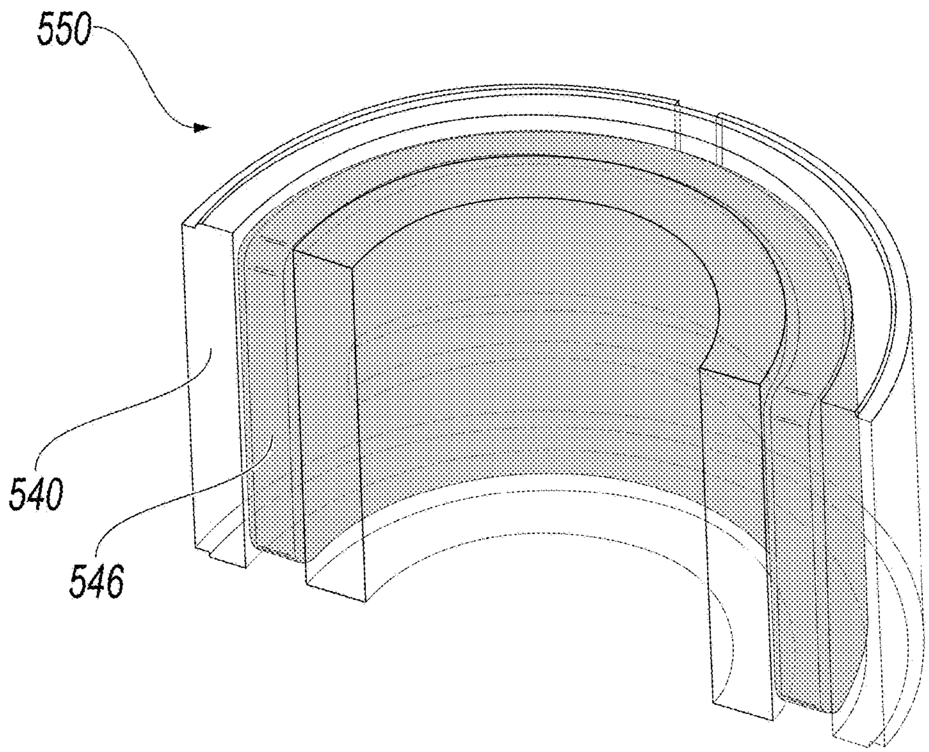
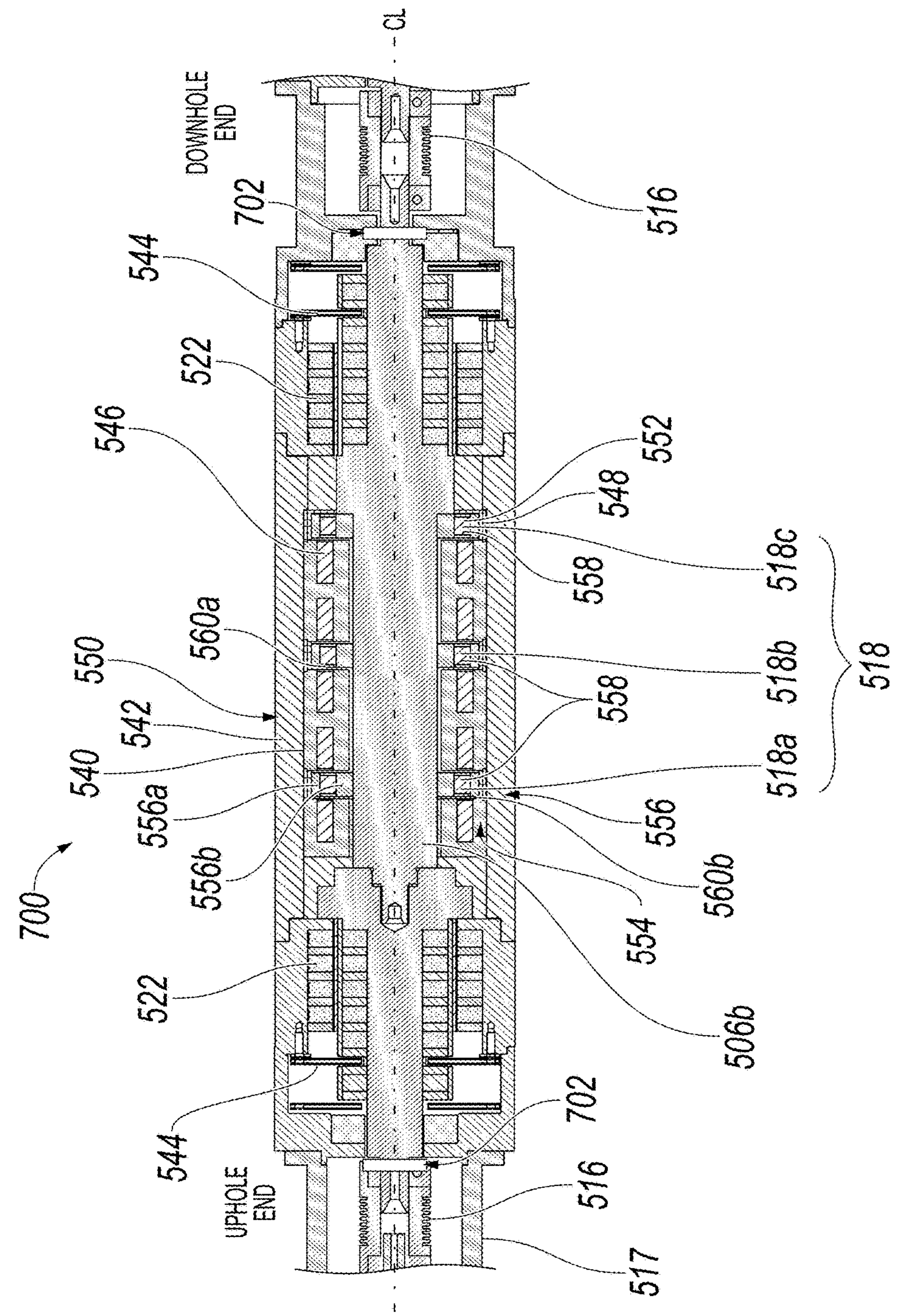


FIG. 6B


CL
DOWNHOLE END
UPHOLE END
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702
516
544
522
546
552
548
558
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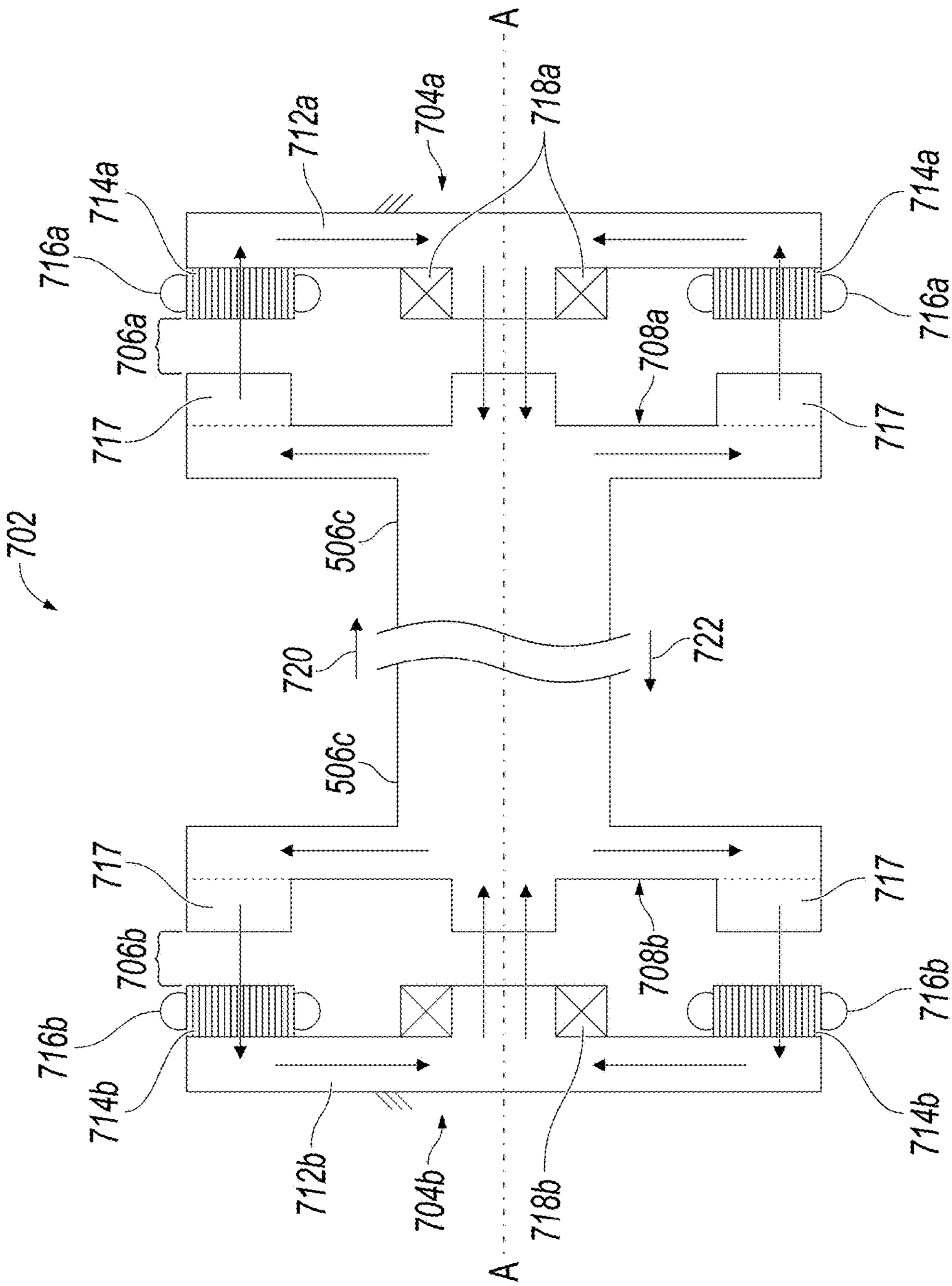
550
560a
542
540
556a
556b
556
560b
554
506b
517

FIG. 7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712a
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716b
717
718a
718b
720
722
506c
A
A

FIG. 8A

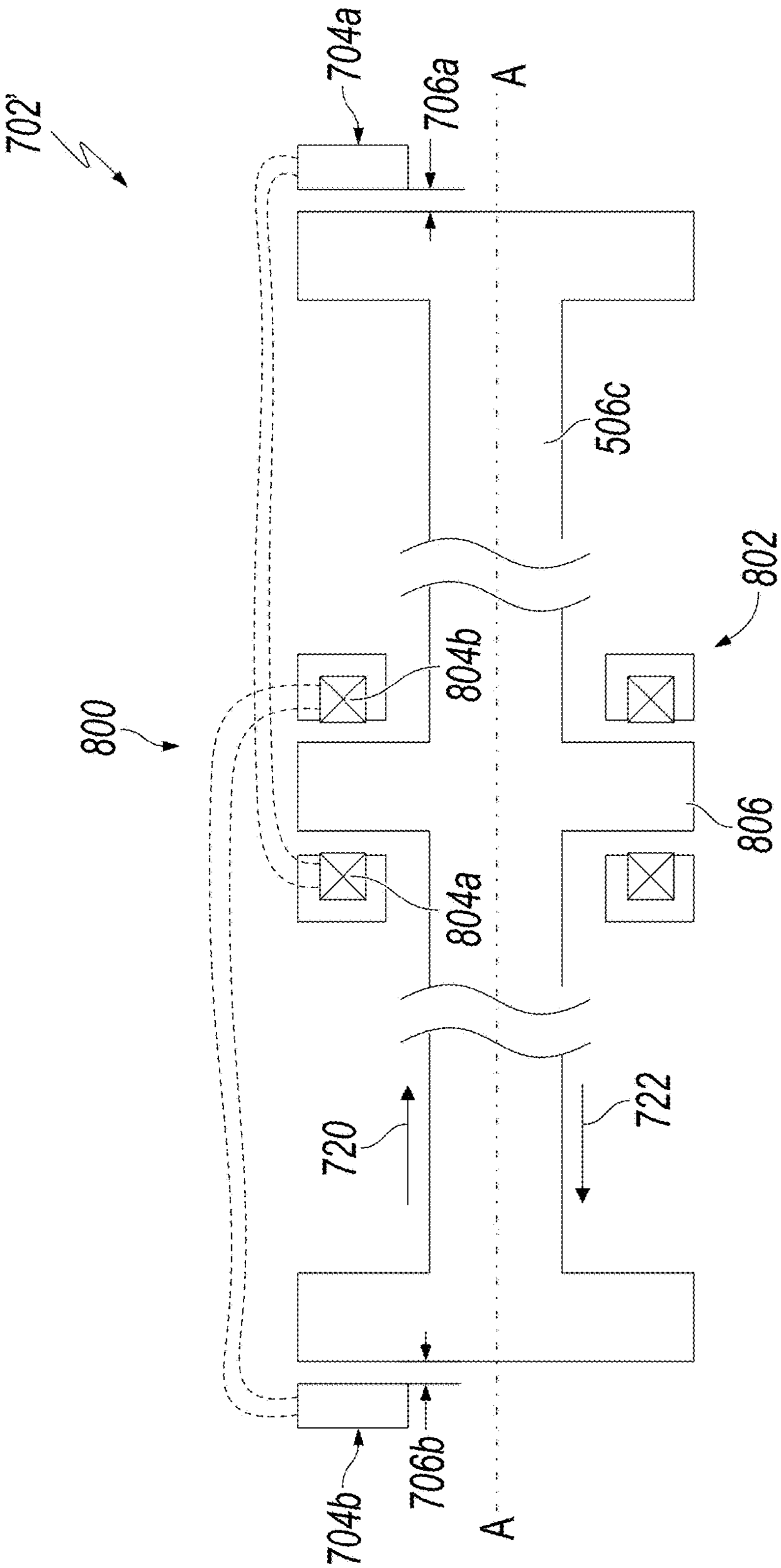
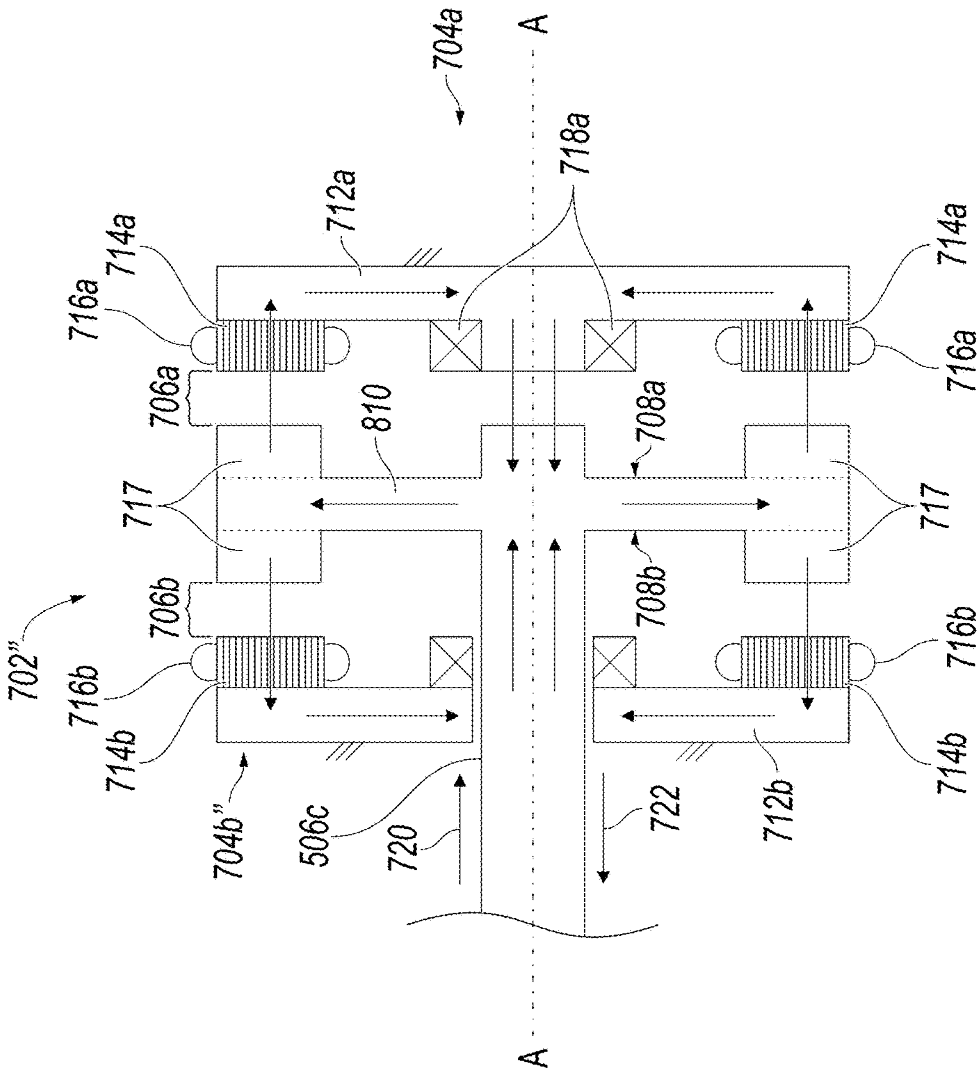


FIG. 8B



704a
A
718a
712a
714a
716a
706a
810
708a
717
702"
706b
708b
716b
714b
704b"
506c
720
722
712b
A

FIG. 8C

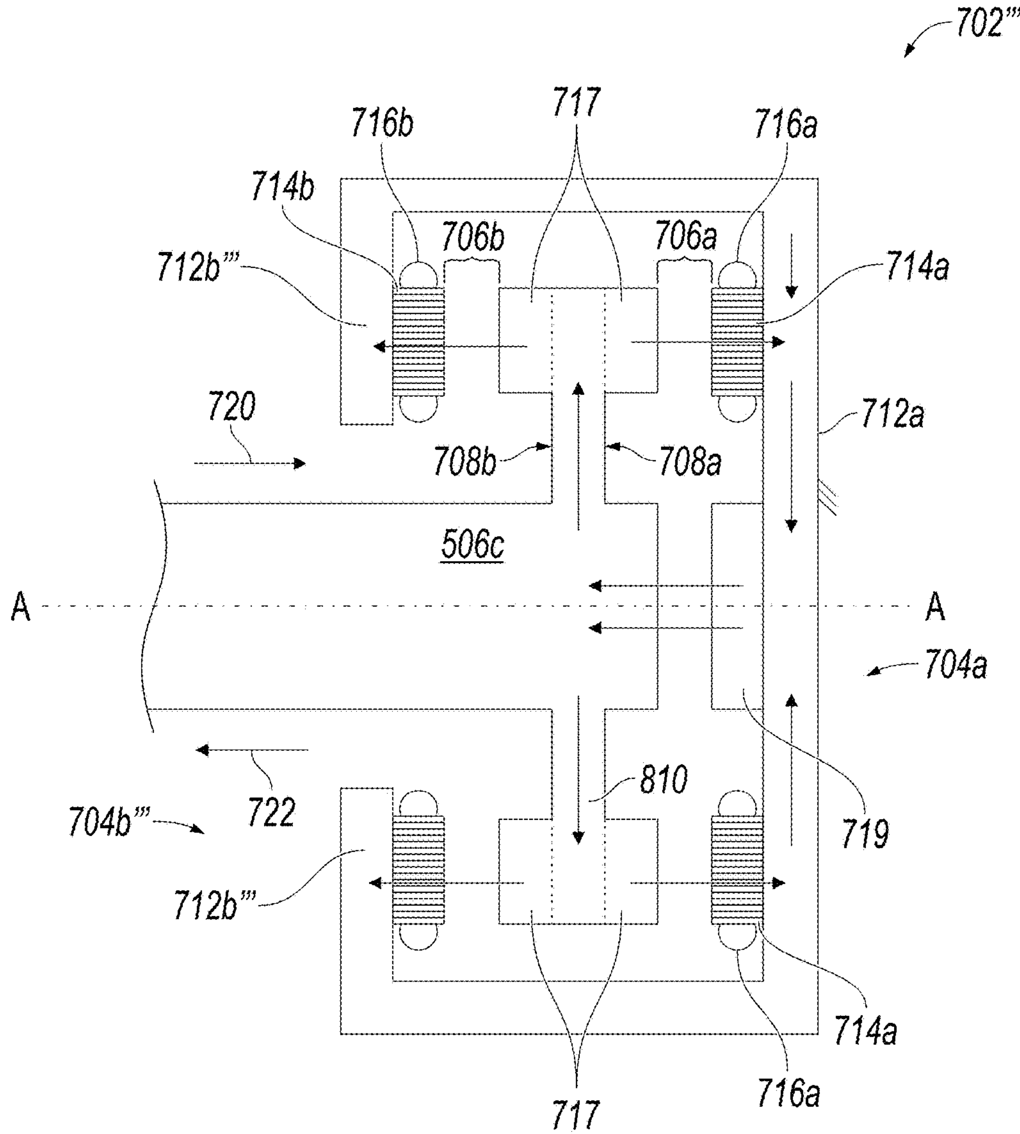

702'''
717
716b
716a
714b
706b
706a
712b'''
714a
720
712a
708b
708a
506c
A
A
704a
810
719
704b'''
722
712b'''
714a
716a
717

FIG. 8D

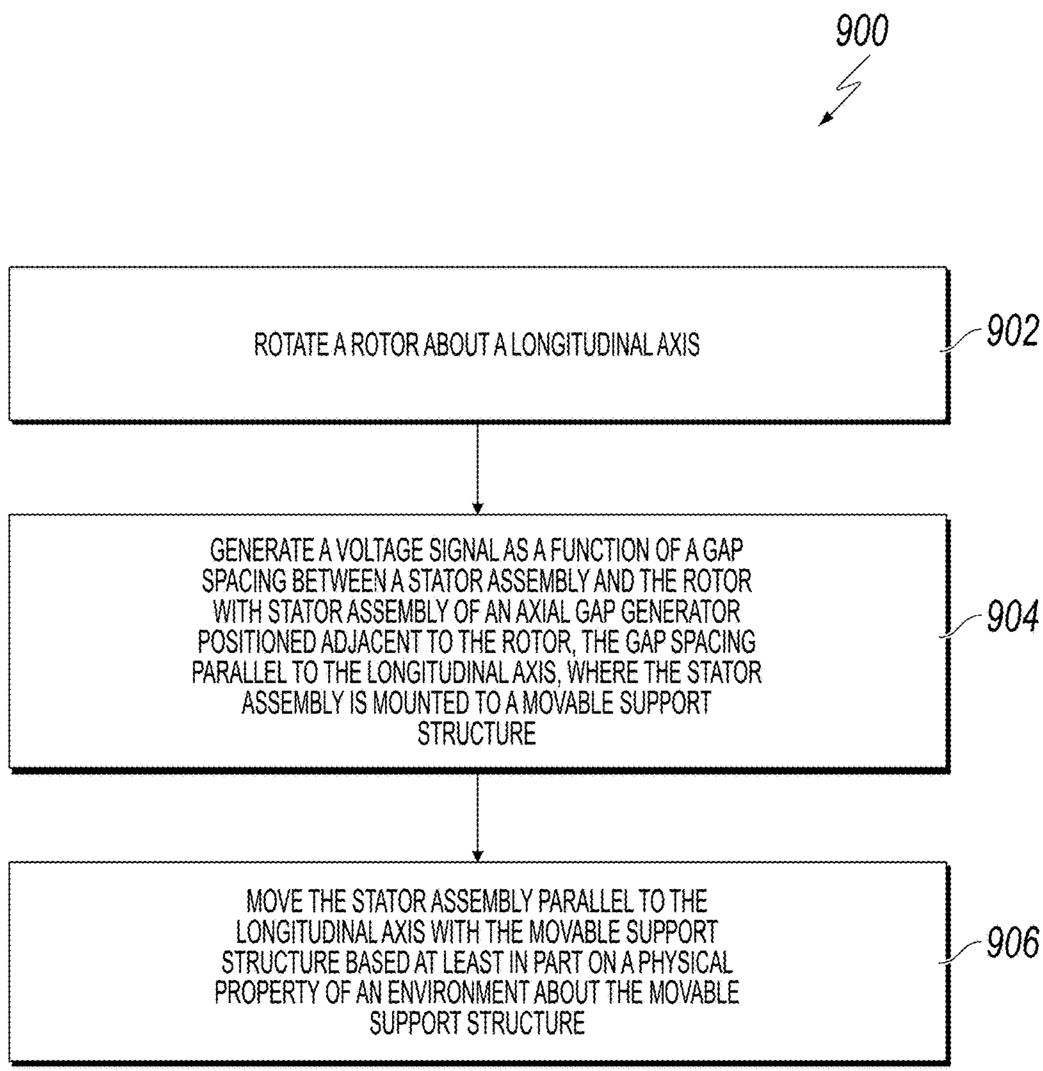

900
ROTATE A ROTOR ABOUT A LONGITUDINAL AXIS
902
GENERATE A VOLTAGE SIGNAL AS A FUNCTION OF A GAP SPACING BETWEEN A STATOR ASSEMBLY AND THE ROTOR WITH STATOR ASSEMBLY OF AN AXIAL GAP GENERATOR POSITIONED ADJACENT TO THE ROTOR, THE GAP SPACING PARALLEL TO THE LONGITUDINAL AXIS, WHERE THE STATOR ASSEMBLY IS MOUNTED TO A MOVABLE SUPPORT STRUCTURE
904
MOVE THE STATOR ASSEMBLY PARALLEL TO THE LONGITUDINAL AXIS WITH THE MOVABLE SUPPORT STRUCTURE BASED AT LEAST IN PART ON A PHYSICAL PROPERTY OF AN ENVIRONMENT ABOUT THE MOVABLE SUPPORT STRUCTURE
906

FIG. 9A

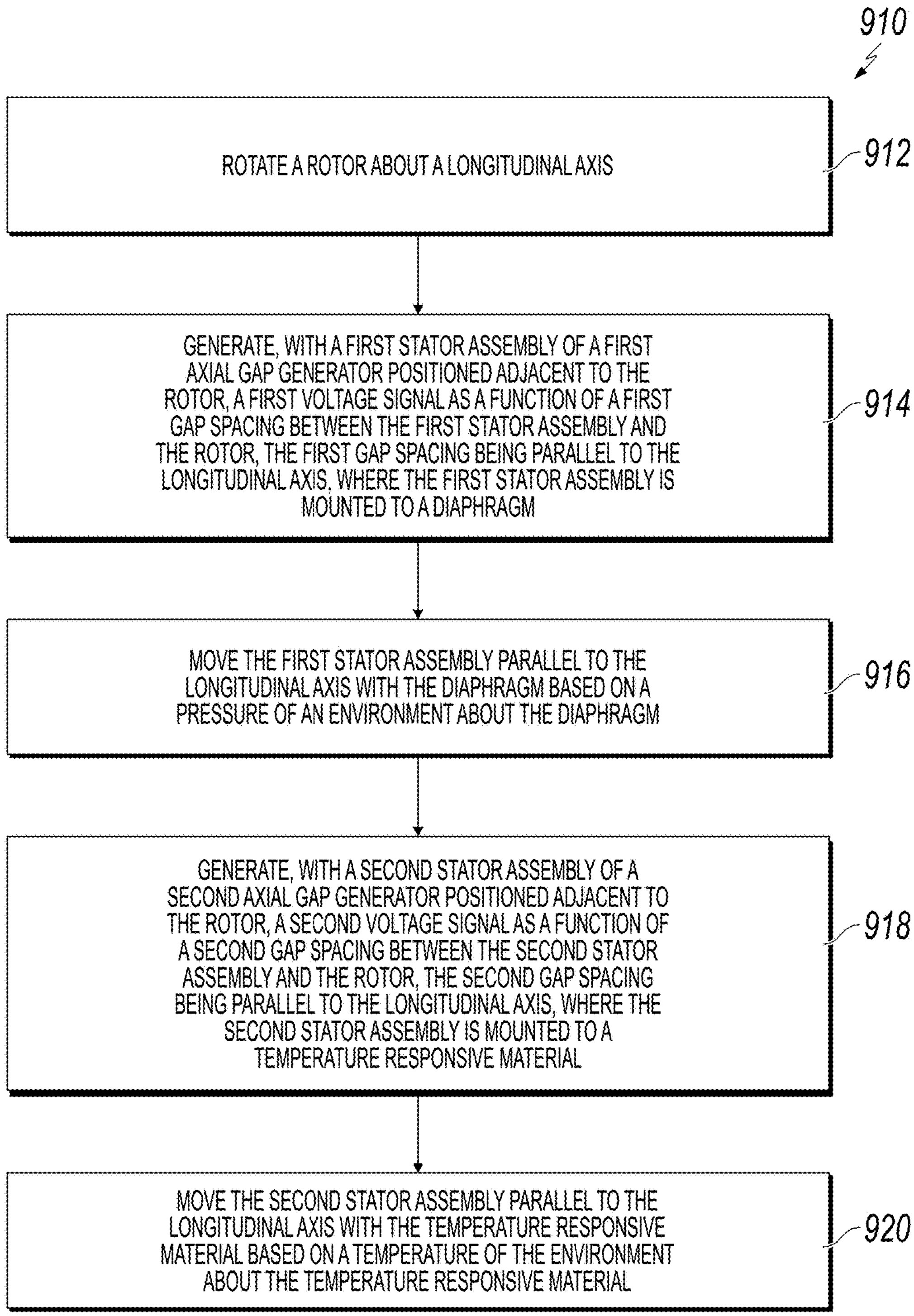

910
ROTATE A ROTOR ABOUT A LONGITUDINAL AXIS
912
GENERATE, WITH A FIRST STATOR ASSEMBLY OF A FIRST AXIAL GAP GENERATOR POSITIONED ADJACENT TO THE ROTOR, A FIRST VOLTAGE SIGNAL AS A FUNCTION OF A FIRST GAP SPACING BETWEEN THE FIRST STATOR ASSEMBLY AND THE ROTOR, THE FIRST GAP SPACING BEING PARALLEL TO THE LONGITUDINAL AXIS, WHERE THE FIRST STATOR ASSEMBLY IS MOUNTED TO A DIAPHRAGM
914
MOVE THE FIRST STATOR ASSEMBLY PARALLEL TO THE LONGITUDINAL AXIS WITH THE DIAPHRAGM BASED ON A PRESSURE OF AN ENVIRONMENT ABOUT THE DIAPHRAGM
916
GENERATE, WITH A SECOND STATOR ASSEMBLY OF A SECOND AXIAL GAP GENERATOR POSITIONED ADJACENT TO THE ROTOR, A SECOND VOLTAGE SIGNAL AS A FUNCTION OF A SECOND GAP SPACING BETWEEN THE SECOND STATOR ASSEMBLY AND THE ROTOR, THE SECOND GAP SPACING BEING PARALLEL TO THE LONGITUDINAL AXIS, WHERE THE SECOND STATOR ASSEMBLY IS MOUNTED TO A TEMPERATURE RESPONSIVE MATERIAL
918
MOVE THE SECOND STATOR ASSEMBLY PARALLEL TO THE LONGITUDINAL AXIS WITH THE TEMPERATURE RESPONSIVE MATERIAL BASED ON A TEMPERATURE OF THE ENVIRONMENT ABOUT THE TEMPERATURE RESPONSIVE MATERIAL
920

FIG. 9B

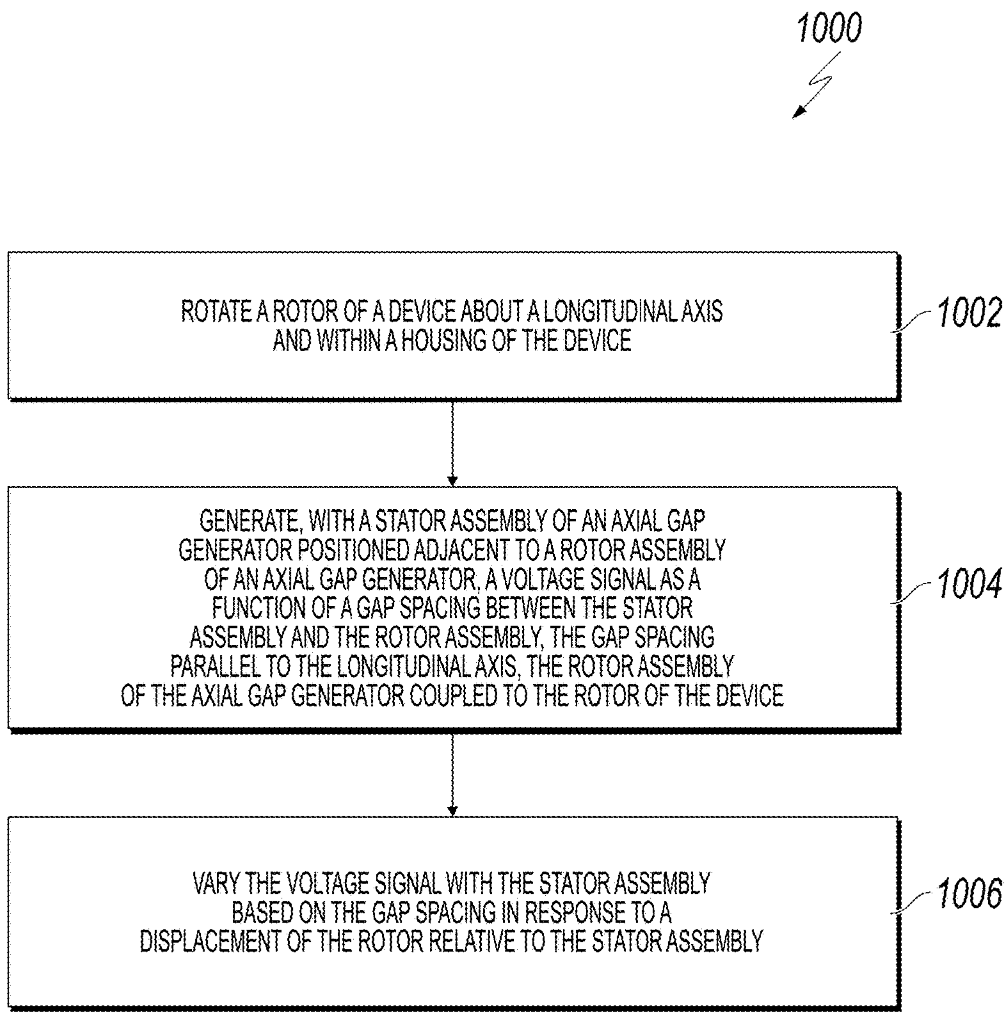

1000
ROTATE A ROTOR OF A DEVICE ABOUT A LONGITUDINAL AXIS AND WITHIN A HOUSING OF THE DEVICE
1002
GENERATE, WITH A STATOR ASSEMBLY OF AN AXIAL GAP GENERATOR POSITIONED ADJACENT TO A ROTOR ASSEMBLY OF AN AXIAL GAP GENERATOR, A VOLTAGE SIGNAL AS A FUNCTION OF A GAP SPACING BETWEEN THE STATOR ASSEMBLY AND THE ROTOR ASSEMBLY, THE GAP SPACING PARALLEL TO THE LONGITUDINAL AXIS, THE ROTOR ASSEMBLY OF THE AXIAL GAP GENERATOR COUPLED TO THE ROTOR OF THE DEVICE
1004
VARY THE VOLTAGE SIGNAL WITH THE STATOR ASSEMBLY BASED ON THE GAP SPACING IN RESPONSE TO A DISPLACEMENT OF THE ROTOR RELATIVE TO THE STATOR ASSEMBLY
1006

FIG. 10

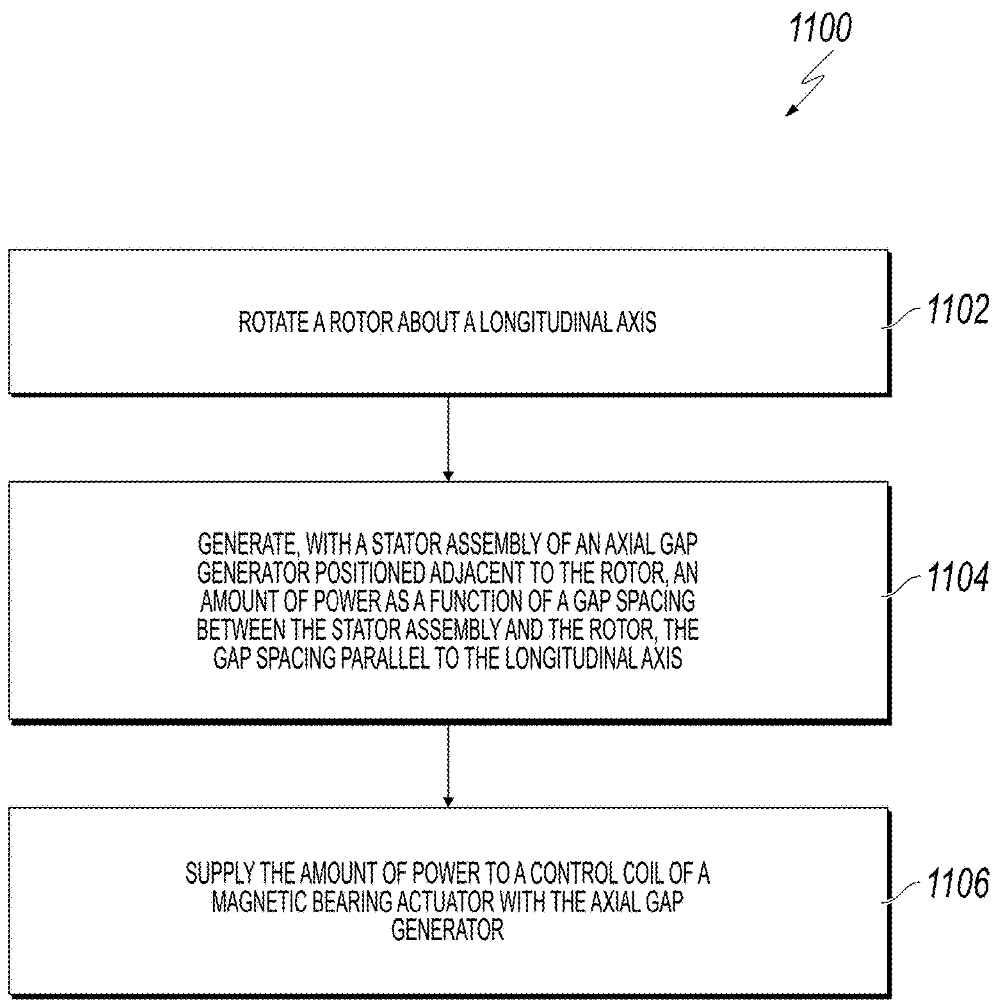

1100
ROTATE A ROTOR ABOUT A LONGITUDINAL AXIS
1102
GENERATE, WITH A STATOR ASSEMBLY OF AN AXIAL GAP GENERATOR POSITIONED ADJACENT TO THE ROTOR, AN AMOUNT OF POWER AS A FUNCTION OF A GAP SPACING BETWEEN THE STATOR ASSEMBLY AND THE ROTOR, THE GAP SPACING PARALLEL TO THE LONGITUDINAL AXIS
1104
SUPPLY THE AMOUNT OF POWER TO A CONTROL COIL OF A MAGNETIC BEARING ACTUATOR WITH THE AXIAL GAP GENERATOR
1106

FIG. 11

AXIAL GAP GENERATOR MEASUREMENT TOOL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Patent Application No. 62/561,067, entitled "Sealless Downhole System with Magnetically Supported Rotor," filed Sep. 20, 2017, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

This disclosure relates to measurement tools and devices incorporating an axial gap generator.

BACKGROUND

Rotating equipment and tools often include a rotor that rotates on a longitudinal axis within a housing of the rotating equipment or tool. Rotating equipment can employ magnetic assemblies, such as magnetic bearings, permanent magnet assemblies, and/or electromagnetic assemblies to provide support and control to a rotor during operation. For example, electric motors and magnetic bearing assemblies intended for downhole environments often incorporate magnetic assemblies to power, control, and support a rotor within the electric motor and magnetic bearing assembly.

SUMMARY

This disclosure describes measurement tools incorporating an axial gap generator to measure axial position or a physical property about the axial gap generator.

In some aspects, a tool includes a device having a housing and a rotor, the rotor to rotate about a longitudinal axis, and an axial gap generator including a stator assembly positioned adjacent to the rotor, the axial gap generator to generate a voltage signal as a function of a gap spacing between the stator assembly and the rotor and parallel to the longitudinal axis.

This, and other aspects, can include one or more of the following features. The device can be a downhole-type device to operate in a downhole wellbore environment. The device can include a motor, a compressor, a blower, a pump, a thrust bearing, or a combination of these. The axial gap generator can determine an axial position of the rotor as a function of the generated voltage signal. The axial gap generator can determine axial position of the rotor for an active axial magnetic bearing system. The axial gap generator can vary the voltage signal based on a variance in the gap spacing in response to a displacement of the rotor relative to the stator assembly and parallel to the longitudinal axis. The stator assembly can include a first stator portion adjacent a first longitudinal side of the rotor, the gap spacing being a first gap spacing, and a second stator portion adjacent a second longitudinal side of the rotor opposite the first longitudinal side of the rotor. The axial gap generator can generate the voltage signal as a function of the first gap spacing between the first stator portion and the first longitudinal side of the rotor and a second gap spacing between the second stator portion and the second longitudinal side of the rotor. The axial gap generator can include a permanent magnet to generate a magnetic field through the axial gap generator. The axial gap generator can include an energized field coil to generate a magnetic field through the axial gap

generator. The axial gap generator can be positioned adjacent to a longitudinal end of the rotor. The voltage signal can be the back electromotive force of the axial gap generator.

Certain aspects of the disclosure encompass a method including rotating a rotor of a device about a longitudinal axis and within a housing of the device, generating, with a stator assembly of an axial gap generator positioned adjacent to a rotor assembly of an axial gap generator, a voltage signal as a function of a gap spacing between the stator assembly and the rotor assembly, the gap spacing parallel to the longitudinal axis, the rotor assembly of the axial gap generator coupled to the rotor of the device, and varying, with the stator assembly, the voltage signal based on the gap spacing in response to a displacement of the rotor relative to the stator assembly.

This, and other aspects, can include one or more of the following features. The device can be a downhole device. The device can be a motor, pump, compressor, blower, or thrust bearing. The stator assembly can be mounted to the housing of the device. The voltage signal can be linearly proportional to the gap spacing. The voltage signal can be non-linearly proportional to the gap spacing. The method can further include receiving, with a controller, the voltage signal from the axial gap generator, and in response to receiving the voltage signal, determining, with the controller, an axial position of the rotor based on the received voltage signal. The method can further include determining, with the controller, a speed of the rotor based on a frequency of the received voltage signal. The method can further include generating, with a second stator assembly of a second axial gap generator positioned adjacent to the rotor assembly of the axial gap generator, a second voltage signal as a function of a second gap spacing between the second stator assembly and the rotor assembly, the second gap spacing parallel to the longitudinal axis, where the second stator assembly voltage signal is combined with the first stator assembly voltage signal to provide one voltage signal proportional to gap spacing. The first stator voltage signal can be 180 electrical degrees out of phase with the second stator voltage signal. The first stator voltage signal can be in phase with the second stator voltage signal. The first stator voltage signal can be of one polarity and the second stator voltage signal can be of the opposite polarity. The first stator voltage signal and the second stator voltage signal can be of one polarity. The method can further include generating, with a second stator assembly of a second axial gap generator positioned adjacent to the rotor assembly of an axial gap generator, a second voltage signal as a function of a second gap spacing between the second stator assembly and the rotor assembly, the second gap spacing parallel to the longitudinal axis, where the second stator assembly is mounted to a movable support structure, and moving, with the movable support structure, the second stator assembly parallel to the longitudinal axis based at least in part on a physical property of an environment about the movable support structure. The method can further include receiving, at a controller, the first-mentioned voltage signal from the first-mentioned axial gap generator and the second voltage signal from the second axial gap generator, determining, with the controller, an axial position of the rotor based on the received first-mentioned voltage signal, and in response to determining the axial position of the rotor, determining, with the controller, the physical property of the environment about the movable support structure based at least in part on the second voltage signal.

The details of one or more implementations of the subject matter described in this disclosure are set forth in the

accompanying drawings and the description below. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic side view of an example well system including a downhole-type tool.

FIG. **2**A is a schematic cross-sectional side view of an example measurement tool adjacent to a rotor.

FIGS. **2**B and **2**C are isometric views of an example rotor, and of an example rotor and example measurement tool, respectively.

FIG. **3** is a schematic cross-sectional side view of an example measurement tool adjacent to a rotor.

FIGS. **4**A-**4**D are schematic cross-sectional side views of example measurement tools adjacent to a rotor.

FIG. **5** is a schematic side half cross-sectional view of an example downhole-type artificial lift system.

FIG. **6**A is a schematic side half cross-sectional view of an example thrust bearing module.

FIG. **6**B is a perspective cut-away view of an example half stator pole.

FIG. **7** is a side cross-sectional view of an example thrust bearing module that incorporates an axial gap generator assembly.

FIGS. **8**A-**8**D are partial schematic cross-sectional side views of an example axial gap generator assembly positioned adjacent to a rotor.

FIGS. **9**A, **9**B, **10**, and **11** are flowcharts describing example methods for using an axial gap generator.

Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

Many devices with rotating rotors incorporate electronics and sensors to provide feedback on operating conditions and environment, and typically include small sensor devices with local electronics that decode a measurement and transmission software to send data reflective of the decoded measurement to a processor separate from the sensors via communication line. However, electronics and sensors are often limited, fragile, and unreliable in harsh environments. For example, in a downhole environment, it is sometimes difficult to reliably measure parameters, and/or control, power, and operate any equipment due to the presence of caustic fluids, pressures, temperatures, and relative distance from any supporting equipment that cannot be repackaged to fit in a small diameter tube. Many electronic devices and sensors placed in a downhole environment are prone to damage and unreliability. In addition, installation and removal of tools in a well often requires the well to be "shutdown" or "killed" to prevent fluid flowing to the surface that can cause damage or injury, a very costly process not only in performing the work but also in lost production and risk in damaging the well where further production is jeopardized.

While all these issues and risks exist for downhole operations, the potential benefit of well intervention with production enhancing tools and measurement equipment is often worth the risk because of the enhanced production it can offer. While these benefits have been demonstrated, reliability and robustness of equipment in this harsh environment is not close to conventional topside mounted equipment. The concepts described herein are able to improve reliability and robustness of equipment by incorporating axial gap generators interacting with a rotating rotor to provide one or more measurements of a physical property of a device or an environment, provide control to a device, and/or generate power for a device, for example, without requiring fragile or sensitive electronic devices to be disposed in a harsh environment such as a downhole environment. For example, the concepts described herein utilize one or more axial gap generators sensitive to an axial gap spacing between a rotor and the axial gap generator for measurements and/or power generation locally at a rotating device, which can be used in a variety of applications, described in more detail later. In some examples, axial generators are incorporated in a magnetic bearing system for rotor support, a magnetic thrust bearing for thrust support, a high speed permanent magnet motor for torque, a sensorless long distance variable frequency drive or variable speed drive, magnetic bearing controls, advanced fluid compression and pump configuration, or a combination of these. The use of axial gap generators allows for reliable measurement of an axial gap spacing between a rotor and the generator, where the axial gap spacing can correspond to an axial position of the rotor, a pressure of a surrounding environment, a temperature of a surrounding environment, and/or an axial force for a corresponding magnetic bearing. For example, the axial gap spacing between the rotor and the axial gap generator can provide an electronic signal (e.g., voltage signal, back electromotive force signal, and/or other signal) reflective of a position, temperature, and/or pressure of or surrounding the rotor, or an amount of power reflective of a magnetic force to bias the rotor in a direction (e.g., to a balanced, neutral position). The axial gap generators described herein provide measurements, control, and/or power, and are more reliable and robust than electronic devices and sensors conventionally used for measurement, control, and/or power, for example, in a downhole environment or other environments.

While axial generators are shown and described later in a well system and incorporated with a downhole-type tool, the axial generators are applicable to tools and devices having a rotatable rotor in above-ground or surface applications, and are not limited to downhole devices and tools. For example, the axial gap generators described herein can be used in a rotating machine, turbocharger, motor, compressor, pump, blower, turbine, thrust bearing assembly, and/or any other rotating equipment.

FIG. **1** is a schematic partial cross-sectional side view of an example well system **100** constructed in accordance with the concepts herein. The well system **100** includes a well **102** having a wellbore **104** that extends from the terranean surface **106** through the earth **108** to one or more subterranean zones of interest **110** (one shown). The well system **100** enables access to the subterranean zones of interest **110** to allow recovery, i.e., production of fluids to the terranean surface **106** and, in certain instances, additionally or alternatively allows fluids to be placed in the earth **108**. In certain instances, the subterranean zone **110** is a formation within the Earth defining a reservoir, but in other instances, the zone **110** can be multiple formations or a portion of a formation. For simplicity sake, the well **102** is shown as a vertical well with a vertical wellbore **104**, but in other instances, the well **102** could be a deviated well with the wellbore **104** deviated from vertical (e.g., horizontal or slanted) and/or the wellbore **104** could be one of the multiple bores of a multilateral well (i.e., a well having multiple lateral wells branching off another well or wells).

In certain instances, the well system **100** is a gas well that is used in producing natural gas from the subterranean zones of interest **110** to the surface **106**. While termed a "gas well," the well need not produce only dry gas, and may incidentally or in much smaller quantities, produce liquid including oil and/or water. In certain instances, the production from the well **102** can be multiphase in any ratio, and/or despite being a gas well, the well can produce mostly or entirely liquid at certain times and mostly or entirely gas at other times. For example, in certain types of wells it is common to produce water for a period of time to gain access to the gas in the subterranean zone. The concepts herein, though, are not limited in applicability to gas wells or even production wells, and could be used in wells for producing liquid resources such as oil, water or other liquid resource, and/or could be used in injection wells, disposal wells or other types of wells used in placing fluids into the Earth.

The wellbore **104** is typically, although not necessarily, cylindrical. All or a portion of the wellbore **104** is lined with a tubing, i.e., casing **112**. The casing **112** connects with a wellhead **118** at the terranean surface **106** and extends downhole into the wellbore **104**. The casing **112** operates to isolate the bore of the well **102**, defined in the cased portion of the well **102** by the inner bore **116** of the casing **112**, from the surrounding earth **108**. The casing **112** can be formed of a single continuous tubing or multiple lengths of tubing joined (e.g., threadingly and/or otherwise) end-to-end. In FIG. **1**, the casing **112** is perforated (i.e., having perforations **114**) in the subterranean zone of interest **110** to allow fluid communication between the subterranean zone of interest **110** and the bore **116** of the casing **112**. In other instances, the casing **112** is omitted or ceases in the region of the subterranean zone of interest **110**. This portion of the wellbore **104** without casing is often referred to as "open hole."

The wellhead **118** defines an attachment point for other equipment of the well system **100** to be attached to the well **102**. For example, FIG. **1** shows well **102** being produced with a Christmas tree **120** attached to the wellhead **118**. The Christmas tree **120** includes valves used to regulate flow into or out of the well **102**.

The well system **100** includes a downhole-type tool **136** with a rotor (not shown) configured to rotate about a longitudinal axis (e.g., parallel to a centerline of the wellbore **104**), and a measurement tool **138** including one or more axial gap generators (not shown) positioned proximate to the rotor of the downhole-type tool **136**. The downhole-type tool **136** can take many forms, and perform a variety of functions based on the type of well operation intended for the well system **100**. For example, the downhole-type tool **136** can include a motor, a compressor, a blower, a pump, an impeller, a thrust bearing assembly, and/or another device that includes a rotor that rotates during operation. The measurement tool **138** includes the one or more axial gap generators, and can attach to or be integral with the downhole-type tool **136** to interact with the rotor and measure a local physical characteristic and/or generate an amount of power. The measurement tool **138** is described in greater detail later. A variable speed drive (VSD) **140** is schematically shown in FIG. **1** as connected to the wellhead **118**. The VSD **140** can provide power and control to the downhole-type tool **136**, as described in more detail later.

In the example well system **100** of FIG. **1**, the downhole-type tool **136** is shown as a downhole-type artificial lift system **124** residing in the wellbore **104**, for example, at a depth that is nearer to subterranean zone **110** than the terranean surface **106**. The example well system **100** also includes a surface compressor or pump **122** residing on the terranean surface **106** and fluidly coupled to the well **102** through the Christmas tree **120**. The surface compressor or pump **122** can include a variable speed or fixed speed compressor. The surface compressor or pump **122** operates to draw down the pressure inside the well **102** at the surface **106** to facilitate production of fluids to the surface **106** and out of the well **102**. The downhole artificial lift system **124**, being of a type configured in size and robust construction for installation within a well **102**, assists by creating an additional pressure differential within the well **102**. In particular, casing **112** is commercially produced in a number of common sizes specified by the American Petroleum Institute (the API), including 4½, 5, 5½, 6, 6⅝, 7, 7⅝, 16/8, 9⅝, 10¾, 11¾, 13⅜, 16, 116/8, and 20 inches, and the API specifies internal diameters for each casing size. The downhole artificial lift system **124** can be configured to fit in, and (as discussed in more detail below) in certain instances, seal to the inner diameter of one of the specified API casing sizes. Of course, the downhole artificial lift system **124** can be made to fit in and, in certain instances, seal to other sizes of casing or tubing or otherwise seal to the wall of the wellbore **104**. While only one downhole-type artificial list system **124** is shown residing in the wellbore **104**, more than one may be used.

Additionally, as a downhole-type tool **136** or any other downhole system configuration such as the downhole type artificial lift system **124**, a pump, compressor, or multi-phase fluid flow aid that can be envisioned, the construction of its components are configured to withstand the impacts, scraping, and other physical challenges the downhole-type tool **136** will encounter while being passed hundreds of feet/meters or even multiple miles/kilometers into and out of the wellbore **104**. For example, the downhole-type tool **136** can be disposed in the wellbore **104** at a depth of up to 20,000 feet (6,100 meters). Beyond just a rugged exterior, this encompasses having certain portions of any electronics being ruggedized to be shock resistant and remain fluid tight during such physical challenges and during operation. Additionally, the downhole-type tool **136** (e.g., the downhole artificial lift system **124**) can be configured to withstand and operate for extended periods of time (e.g., multiple weeks, months, or years) at the pressures and temperatures experienced in the wellbore **104**, which can exceed 400° F./205° C. and pressures over 2,000 pounds per square inch/13,790 kPa, and while submerged in the well fluids (gas, water, or oil as examples). Finally, as a downhole-type tool **136**, the downhole-type tool **136** can be configured to interface with one or more of the common deployment systems, such as jointed tubing (i.e., lengths of tubing joined end-to-end, threadingly and/or otherwise), a sucker rod, coiled tubing (i.e., not-jointed tubing, but rather a continuous, unbroken, and flexible tubing formed as a single piece of material), or wireline with an electrical conductor (i.e., a monofilament or multifilament wire rope with one or more electrical conductors, sometimes called e-line) and thus have a corresponding connector (e.g., a jointed tubing connector, coiled tubing connector, or wireline connector). In FIG. **1**, the downhole-type tool **136** is shown deployed on wireline **128**.

In some implementations, a seal system **126** is integrated or provided separately with the downhole-type tool **136**, as shown in FIG. **1** as with the downhole-type artificial lift system **124**. The seal system **126** divides the well **102** into an uphole zone **130** above the seal system **126** and a downhole zone **132** below the seal system **126**. FIG. **1** shows the downhole-type artificial lift system **124** positioned in the open volume of the bore **116** of the casing **112**, and not within or a part of another string of tubing in the well **102**.

The wall of the wellbore **104** includes the interior wall of the casing **112** in portions of the wellbore **104** having the casing **112**, and includes the open hole wellbore wall in uncased portions of the wellbore **104**. Thus, the seal system **126** is configured to seal against the wall of the wellbore **104**, for example, against the interior wall of the casing **112** in the cased portions of the wellbore **104** or against the interior wall of the wellbore **104** in the uncased, open hole portions of the wellbore **104**. In certain instances, the seal system **126** can form a gas and liquid tight seal at the pressure differential the artificial lift system **124** creates in the well **102**. In some instances, the seal system **126** of the downhole-type artificial lift system **124** seals against the interior wall of the casing **112** or the open hole portion of the wellbore **104**. For example, the seal system **126** can be configured to at least partially seal against an interior wall of the wellbore **104** to separate (completely or substantially) a pressure in the wellbore **104** downhole of the seal system **126** of the downhole-type artificial lift system **124** from a pressure in the wellbore **104** uphole of the seal system **126** of the downhole-type artificial lift system **124**. Although FIG. **1** includes both the surface compressor or pump **122** and the artificial lift system **124**, in other instances, the surface compressor or pump **122** can be omitted and the artificial lift system **124** can provide the entire pressure boost in the well **102**.

In some implementations, the downhole type artificial lift system **124** can be implemented to alter characteristics of a wellbore by a mechanical intervention at the source. Alternatively or in addition to any of the other implementations described in this disclosure, the downhole type artificial lift system **124** can be implemented as a high flow, low pressure rotary device for gas flow in sub-atmospheric wells. Alternatively or in addition to any of the other implementations described in this disclosure, the downhole type artificial lift system **124** can be implemented in a direct well-casing deployment for production through the wellbore. While the downhole type artificial lift system **124** is described in detail as an example implementation of the downhole-type tool **136**, alternative implementations of a downhole system as a pump, compressor, or multiphase combination of these can be utilized in the wellbore **104**, for example, to effect increased well production.

The downhole-type tool **136** is shown in FIG. **1** as the downhole artificial lift system **124**, which can locally alter the pressure, temperature, and/or flow rate conditions of the fluid in the wellbore **104** proximate the artificial lift system **124** (e.g., at the base of the wellbore **104**). In certain instances, the alteration performed by the artificial lift system **124** can improve, optimize, or help in optimizing fluid flow through the wellbore **104**. As described above, the downhole-type artificial lift system **124** creates a pressure differential within the well **102**, for example, particularly within the wellbore **104** where the artificial lift system **124** resides. In some instances, a pressure at the base of the wellbore **104** is a low pressure (e.g., sub-atmospheric); so unassisted fluid flow in the wellbore can be slow or stagnant. In these and other instances, the downhole-type artificial lift system **124** introduced to the wellbore **104** adjacent the perforations **114** can reduce the pressure in the wellbore **104** near the perforations **114** to induce greater fluid flow from the subterranean zone **110**, increase a temperature of the fluid entering the artificial lift system **124** to reduce condensation from limiting production, and increase a pressure in the wellbore **104** uphole of the artificial lift system **124** to increase fluid flow to the surface **106**.

The artificial lift system **124** moves the fluid at a first pressure downhole of the blower to a second, higher pressure uphole of the artificial lift system **124**. The artificial lift system **124** can operate at and maintain a pressure ratio across the artificial lift system **124** between the second, higher uphole pressure and the first, downhole pressure in the wellbore. The pressure ratio of the second pressure to the first pressure can also vary, for example, based on an operating speed of the artificial lift system **124**, as described in more detail below.

The downhole-type artificial lift system can operate in a variety of downhole conditions of the wellbore **104**. For example, the initial pressure within the wellbore **104** can vary based on the type of well, depth of the well **102**, production flow from the perforations into the wellbore **104**, and/or other factors.

In some implementations, a magnetic bearing controller and amplifier drive **150** for the downhole-type tool **136**, shown as the downhole-type artificial lift system **124** in FIG. **1**, is located topside to improve and/or maximize reliability and serviceability. A digital signal processor (DSP) based controller receives signals, such as position signals, from an axial generator, sensor, and/or sensor electronics within the downhole-type tool **136**, and uses the signals for input as part of an algorithm to determine a property of the tool **136** (e.g., rotor position) and/or an environment about the tool **136**. For example, the algorithm can include a position control algorithm to determine a longitudinal position and/or lateral position of the rotor of the tool **136**, for example, relative to a longitudinal axis parallel to (substantially or exactly) the centerline of the wellbore **104**. This algorithm output can include a current command to an amplifier to drive coils of the active magnetic bearings within the downhole-type artificial lift system **124**, thus impacting a force on the rotor (details are explained in greater detail later within the disclosure). This loop can happen very fast, on the order of 1,000-20,000 times a second depending on the system control requirements. However, all or a portion of the control measurements can be measured at a lower rate. This control system is also capable of interpreting the bearing requirements to estimate forces and fluid pressures in the well. An analog circuit based controller can also perform this function. Having this DSP or analog circuit based controller topside allows for easy communication, service, and improved up time for the system, as any issues can be resolved immediately via local or remote support. Downhole electronics are also an option either proximate to the device or at a location more thermally suitable. In a downhole implementation, the electronics can be packaged to isolate them from direct contact with the downhole environment. Downhole electronics offer better control options since they don't suffer with long cable delay and response issues. In certain implementations, the one or more axial gap generators of the measurement tool **138** adjacent the rotor of the downhole-type tool **136** can operate to measure a physical property of the rotor or the environment surrounding the generator, and/or generate and supply power to the control coils of one or more magnetic bearings, for example, to reduce or remove the use of fragile downhole electronics to measure physical properties downhole and/or control the one or more magnetic bearings. Details of these implementations are explained in greater detail later.

FIG. **2A** is a schematic cross-sectional side view of an example measurement tool **200** adjacent to a rotor **202**. The example measurement tool **200** can be used in the measurement tool **138** of FIG. **1**, and the rotor **202** can be the rotor of the downhole-type tool **136** of FIG. **1**. The measurement tool **200** measures an axial position of the rotor **202**, for example, along a longitudinal axis A-A about which the rotor **202** is configured to rotate. The measurement tool **200** includes an axial gap generator **206** including a stator assembly **208** that is sensitive to an axial gap **210** between the rotor **202** and the stator assembly **208**, and parallel to the longitudinal axis A-A. During operation of a tool (e.g., a downhole-type tool) that rotates the rotor **202**, the measurement tool **200** can be used to measure an axial position of the rotor **202** as the rotor **202** rotates about the longitudinal axis A-A and as the rotor **202** is displaced along the longitudinal axis A-A, for example, in response to fluctuations in an environment surrounding the tool, fluctuations in an operation of the tool, and/or other factors.

The axial gap generator **206** generates an electrical signal (e.g., voltage signal) as a function of the gap spacing **210** between the stator assembly **208** and the rotor **202**, where the gap spacing is parallel to the longitudinal axis A-A. The size of the axial gap spacing **210** determines the voltage signal output of the axial gap generator **206**. In some instances, the voltage signal output is a back electromotive force output of the axial gap generator **206**. The axial gap generator **206** varies the voltage signal output reflective of a variance in the gap spacing **210**, for example, in response to a displacement of the rotor **202** relative to the stator assembly **208** and parallel to the longitudinal axis A-A. For example, when the rotor **202**, the stator assembly **208**, or both the rotor **202** and the stator assembly **208** moves relative to one another with respect to the longitudinal axis A-A, the gap spacing **210** between the rotor **202** and the stator assembly **208** changes, and a flux across the gap spacing **210** reaching the stator assembly **208** changes; thus the axial gap generator **206** produces a different voltage signal output as the gap spacing **210** varies. In some examples, the stator assembly **208** is mounted to a housing or other fixed structure, while the rotor **202** is designed to longitudinally displace to some degree (for example, up to the size of the gap spacing **210**) during operation. The axial gap generator **206** can determine the longitudinal position of the rotor **202** because the voltage signal is reflective of the gap spacing **210** between the rotor **202** and the fixed-position stator assembly **208**. As an example, the axial gap generator **206** can generate a voltage signal output of 100 volts alternating current (VAC) when the axial gap spacing **210** is 1 millimeter (mm), while the generator **206** can generator a voltage signal output of 200 VAC when the axial gap spacing **210** is 0.5 mm. While the axial gap generator **206** can have a voltage signal output that is linearly proportional to a size of the gap spacing **210**, the voltage signal output can also be non-linearly proportional to the size of gap spacing.

In the example measurement tool **200** of FIG. **2**A, the stator assembly **208** includes a stator back structure **212**, a set of stator poles **214**, and a set of stator coils **216** surrounding each stator pole **214** in the set of stator poles **214**. The axial gap generator **206** generates the voltage signal as a function of the gap spacing **210** between the stator assembly **208** and the rotor **202**, for example, between the set of stator poles **214** and rotor poles **204** of the rotor **202**. The example stator assembly **208** also includes a magnetic field source in the form of a field coil **218**, where the axial gap generator **206** is an electromagnetic-type generator. The field coil **218** can be connected to a local power source or other power source to provide a current to the axial gap generator **206**. In some embodiments, the axial gap generator **206** is a permanent magnet-type generator, where the field source includes a permanent magnet, for example, instead of the electromagnetic field coils **218**. In permanent magnet-type embodiments, a power source is not needed, as the permanent magnet provides a magnetic field source that does not require a current from a power source to energize the axial gap generator. In some examples, the permanent magnet can be mounted to or integral with the rotor **202**. During operation of a device that rotates the rotor **202**, the magnetic field source (e.g., the energized field coil **218** or a permanent magnet) generates a magnetic field path (indicated in FIG. **2**A with arrows **220**) and a magnetic flux proportional to a current (I) applied to the field coil **218**, a number of turns (N) on the field coil **218** (where magnetomotive force, or mmf, is equal to N×I), and the reluctance of the magnetic field path. The materials of the stator back structure **212**, the rotor **202**, or both can be chosen to reduce its influence on the reluctance of the magnetic field path. For example, the stator back structure **212** and/or the rotor **202** can be comprised of iron because of iron's high magnetic permeability (e.g., μ=2000). However, the material of the rotor **202** and/or the stator back structure **212** can be different. In some examples, the reluctance of the flux path through the stator back structure **212** is very low in relation to the reluctance across the gap spacing **210** because of the low permeability of any fluid in the gap spacing (e.g., μ=1 for air). Magnetic flux is equal to mmf over reluctance (or, mmf/reluctance), so an amount of flux reaching the stator coils **216** is substantially influenced by the gap spacing **210**. As the rotor **202** moves longitudinally (i.e., axially along longitudinal axis A-A), the reluctance of the magnetic field path changes, thus changing the flux seen by the stator coils **216**. The voltage signal output from the axial gap generator **206**, in particular, the stator coils **216**, is dependent on the rotational speed of the rotor **202** and the flux. At a fixed rotational speed of the rotor **202**, the voltage signal output of the axial gap generator **206** is primarily reflective of the gap spacing **210** between the rotor **202** and the stator assembly **208**, so the voltage signal output is representative of the axial position of the rotor **202** relative to the stator assembly **208**. In instances where the stator assembly **208** is in a fixed or known axial position, the voltage signal output from the axial gap generator **206** provides an axial position of the rotor **202**.

FIGS. **2**B and **2**C are isometric views of the example rotor **202**, and of the example rotor **202** and example measurement tool **200**, respectively. Referring to the example rotor **202** and example measurement tool **200** of FIGS. **2**A-**2**C, the rotor **202** includes a two-pole structure including two rotor poles **204** spaced opposite each other on a cylindrical, flanged longitudinal end of the rotor **202**. The rotor poles **204** can be integral to the structure of the rotor **202**, and are shown as extending from the longitudinal end of the rotor **202** across from the stator poles **214** of the stator assembly **208**. In some instances, a different (e.g., greater) number of rotor poles **202** can be used, for example, two, four, six, or more poles can be provided on the rotor **202**. In some instances, rotor poles with side ends of a shorter or longer angular length than the rotor poles **202** shown in FIGS. **2**B and **2**C can be used, for example, rotor poles with side ends having an angular length of 30 degrees (°), 45°, 60°, or 90°, or can be provided on the rotor **202**. As the rotor **202** rotates, the rotor poles **204** create small axial gap areas (e.g., gap spacing **210**) and large axial gap areas between the rotor **202** and the stator assembly **208** corresponding to where the rotor poles **202** extend from the end of the rotor **202** and do not extend from the rotor **202**, respectively. The magnetic flux pathway crosses from rotor pole **204** to stator assembly **208** across the small gap areas (e.g., across gap spacing **210**).

In some instances, the stator assembly **208** is a slotted, laminated soft iron for the high frequency magnetic field. For example, the stator assembly **208** of FIGS. **2**A and **2**C include individual stator poles **214** extending longitudinally from the stator back structure **212** with stator coils **216** wrapped around each stator pole **214**. In some examples, the stator assembly includes a tape-wound laminated core with slots and a subsequent distributed winding (e.g., coils wrapping between slots). Laminations can minimize eddy current generation that would reduce the magnetic field being seen by the stator coils **216** for voltage signal output generation. An isolation can or seal (not shown) can be used in the gap spacing **210**, for example, to prevent or reduce infiltration of materials (e.g., fluids) from affecting operation of the axial gap generator **206**.

The axial gap generator **206** is shown in FIGS. **2**A-**2**C as positioned at the longitudinal end of the rotor **202**, where the stator assembly **208** is positioned adjacent to but spaced slightly apart from the longitudinal end of the rotor **202**. In particular, the rotor **202** includes a flanged end that protrudes radially from a central cylindrical portion of the rotor **202**, and the flanged end includes and/or supports the rotor poles **204**. In some implementations, the axial gap generator **206** can be positioned differently with respect to the rotor **202**. For example, rotor **202** can include a disc-shaped protrusion extending radially outward from the rotor **202** where the central cylindrical portion of the rotor extends longitudinally from both sides of the disc-shaped protrusion, and the stator of the axial gap generator **206** is positioned adjacent to but spaced slightly apart from the disc-shaped protrusion of the rotor **202**. The stator assembly of the axial gap generator can include an aperture through a center of the stator assembly through which the central cylindrical portion of the rotor **202** can pass through, for example, such that the axial gap generator can be positioned along an intermediate length of the rotor between a first longitudinal end and a second, opposite longitudinal end of the rotor. The portion of the rotor engaged with, integrated with, and/or passing through the axial gap generator can be integrated into another component of the rotating device, such as in the end of the motor rotor, thrust bearing, a pump impeller, a compressor wheel, or a turbine wheel, among other rotating device examples.

The stator assembly **208** of the example measurement tool **200** is mounted to a fixed structure with a known axial position. For example, the stator assembly **208** can be mounted to a housing of the measurement tool **200**, a housing of the device supporting the rotor **202**, or another structure. In some examples, the measurement tool **200** includes a housing that is integral with or mounted to a housing of the downhole-type tool **136** of FIG. **1**. The stator assembly **208** is mounted to a fixed structure with a known position, for example, such that a voltage output signal from the axial gap generator **206** corresponding to the gap spacing between the stator assembly **208** and the rotor **202** is reflective of (e.g., a function of) an axial position of the rotor **202**.

The measurement tool **200**, specifically the axial gap generator **206**, is communicably coupled to a controller **222** that receives the voltage signal output from the axial gap generator **206**. The controller **222** receives the voltage signal output, and determines the axial position of the rotor **202** as a function of, or based on, the received voltage signal. The voltage signal output from the axial gap generator **206** can be affected by the operational speed of the rotor **202**. In some implementations, an operating speed (e.g., rotational speed) of the rotor **202** is known, and the controller **222** can incorporate a speed compensation curve in its processing of the received voltage output signal to separate speed from the position signal. In certain implementations, the voltage signal output from the axial gap generator **206** is used to detect the speed of the rotor **202**, for example, using the frequency of the voltage output signal (e.g., VAC) from the axial gap generator **206** since the frequency is directly proportional to operating speed. To determine an axial position of the rotor **202**, a center (e.g., neutral) position of the rotor **202** and a corresponding output signal is established. For example, at a first, neutral position of the rotor **202**, the axial gap generator **206** produces a first voltage output signal. In operation of the rotor **202** and the axial gap generator **206**, a change in the voltage output signal relative of the first voltage output signal signifies a change in the axial position of the rotor **202** with respect to the first, neutral position. The first, neutral position of the rotor **202** and the first voltage output signal can be established with a calibration routine. For example, in an active magnetic bearing system, a calibration routine can include spinning the rotor **202** about its rotational axis (i.e., longitudinal axis A-A) and moving the rotor from a first extreme end (i.e., a maximum displacement in a first direction along the longitudinal axis A-A) to a second, opposite extreme end (i.e., a maximum displacement in a second direction opposite the first direction along the longitudinal axis A-A) to determine a mid-point of the rotor **202** between the first extreme end and the second extreme end. The mid-point of the rotor **202** is the mechanical center of the rotor **202** in relation to the voltage signal from the axial gap generator **206**. The controller **222** can receive voltage signal outputs from the axial generator **206** during rotation of the rotor **202** at a range of frequencies. For example, in instances where a total axial movement of 1 mm is allowed for a rotor assembly, moving the rotor to a first extreme and a second, opposite extreme would allow the controller to determine a center position as 0.5 mm from either side. This movement range can be smaller or larger than 1 mm, but can be expected to be between 0.5 mm to 2 mm.

The axial gap generator **206** can connect to the controller **222** in a variety of ways, such as a wired connection. The controller **222** can be located locally, in other words, close to the axial gap generator **206**. In some examples, the controller **222** is located remotely from the axial gap generator **206**, such as at a tophole location in the well system **100** of FIG. **1**. For example, the axial gap generator **206** can utilize a multi-conductor cable to carry a three-phase voltage signal from the axial gap generator to a tophole controller. This signal could also be generated by the axial gap generator as a single phase or two phase signal and carried on a single or multi-conductor cable. For example, the axial gap generator **206** can tap into a communication line of a variable speed drive (VSD) (e.g., VSD **140** of FIG. **1**) extending from a remote location toward the measurement tool **200** to send the voltage signal output to the controller **222**. In some examples, with reference to the well system **100** of FIG. **1**, the controller **222** is part of the magnetic bearing controller and amplifier drive **150**.

In some implementations, the measurement tool **200** can include a second axial gap generator with a second stator assembly and corresponding structures adjacent to the rotor **202**. The second axial gap generator can produce a second voltage signal output as a function of a second gap spacing between the second stator assembly and a rotor (e.g., rotor **202**) parallel to the longitudinal axis A-A. The second gap generator and second stator assembly can be incorporated into the first stator assembly but configured to output a second voltage signal, or the second gap generator can be positioned separately from the first axial generator **206**, for example, but adjacent to a different portion of the rotor **202**. In some implementations, the voltage signal output from the axial gap generator **206** and the second voltage signal output from the second axial gap generator can be combined to provide a single voltage signal proportional to the respective gap spacings and reflective of the axial position of the rotor **202**. For example, as the first gap spacing **210** on the first axial gap generator **206** is decreased due to rotor **202** displacement, thus increasing its voltage output signal, the second gap spacing between the second axial gap generator and the rotor **202** increases, thus reducing the second voltage output signal from the second gap generator. Putting these two waveforms (i.e., voltage signals) out of phase from each other can increase the sensitivity of the position measurement (e.g., by two-times sensitivity), where in an instance when the rotor **202** is centered, both waveforms are of equal magnitude and as the gap spacings change, the two phases increase and/or reduce proportionally to the change in rotor **202** position. The second axial gap generator can act as a redundant generator to generator **206**. The second axial gap generator can share the same rotor **204**, using a back, or opposite side of the rotor **202** in relation to the stator back structure **212**, or can utilize its own rotor and stator assembly near or distant form the first axial gap generator **206**. In some implementations, a second axial gap generator can act to average position control in a long shaft. Placing a second axial gap generator in a different location from a first axial gap generator to measure position allows an averaging of the position measurements. For example, if a long rotor with many axial components are needed to be controlled axially, one position sensor on one end may not adequately control the far end components. Placing a second axial gap generator at the far end of the rotor and combining the two readings will allow for averaging, for example, reducing inaccuracy in position readings across a rotor where one end sees a displacement that is different from the opposite end. This can occur due to differential thermal growth of components, where the rotor grows axially different than the stator as it changes temperature. The second voltage signal can be in phase or out of phase (e.g., 180 degrees out of phase) with the voltage signal of the axial generator **206**, and can be of the same polarity or opposite polarity as the voltage signal of the axial generator **206**.

The stator assembly **208** can take a variety of other forms. For example, FIG. **3** is a schematic cross-sectional side view of an example measurement tool **300** adjacent to the rotor **202** of FIG. **2**A, where the example measurement tool **300** is like the measurement tool **200** of FIG. **2**A except the stator assembly **208'** of the axial gap generator **206'** has a first stator portion **302** adjacent the rotor **202** and a second stator portion **304** that extends radially outward and around the flanged longitudinal end of the rotor **202**. In addition, the magnetic field source is a permanent magnet **306**, for example, instead of energized electromagnetic field coils. FIG. **3** shows the permanent magnet **306** as attached to or integral with the stator assembly **208'**. In some implementations, the permanent magnet **306** can be attached to the rotor **202**, instead. In the example magnetic tool **300**, the axial gap generator **206'** generates a voltage signal as a function of the gap spacing **210** (i.e., a first gap spacing) between the first stator portion **302** of the stator assembly **208'** and the rotor **202** on a first side of the rotor **202**, and as a function of a second gap spacing **310** between the second portion **304** of the stator assembly **208'** and the rotor **202** on a second side of the rotor **202** opposite the first side. The second gap spacing **310** can be the same size or slightly greater than the gap spacing **210** when the rotor **202** is in its first, neutral position.

During operation of a device that rotates the rotor **202**, the magnetic field source generates the magnetic field path indicated in FIG. **3** with arrows **308**. The magnetic field path **308** includes the magnetic field path **220** of FIG. **2**A crossing the axial gap spacing **210** to the first stator portion **302** of the stator **208'**, and also includes a second magnetic field path section that crosses the second gap spacing **310** on the second side of the rotor **202** through the second stator portion **304** of the stator assembly **208'**. This second path section does not generate a voltage in the stator coils **216** because it does not pass through the stator poles **214**. During operation and rotation of the rotor **202**, the magnetic field path **308** favors the path with the smaller of the two axial gap spacings **210** or **310**. For example, as the rotor **202** moves closer to the first stator portion **302** of the stator assembly **208'** in a first direction **312** (i.e., in a direction from the first side of the rotor **202** toward the first stator portion **302**), the first axial gap **210** becomes smaller and the second axial gap **310** becomes larger, biasing more magnetic field to move across the first gap spacing **210** than the second gap spacing **310**. On the other hand, as the rotor **202** moves closer to the second stator portion **304** of the stator assembly **208'** in a second direction **314** (i.e., in a direction from the second side of the rotor **202** toward the L-shaped second stator portion **304**) opposite the first direction **312**, the second axial gap **310** becomes smaller and the first axial gap **210** becomes larger, biasing more magnetic field to move across the second gap spacing **310** than the first gap spacing **210**. Since the second path of the magnetic field path **308** does not generate a voltage on the stator coils **216**, the stator coils **216** experience a more significant field loss from axial position changes in the second direction **314** (relative to the first, neutral position of the rotor **202**). This arrangement of the stator assembly **208'** can make the axial gap generator **206'** more sensitive to axial position of the rotor **202**, in that the voltage signal output from the axial gap generator **206'** is more sensitive to the axial position of the rotor **202**. Said differently, the amount of flux reaching the stator coils **216** determines the voltage output signal, but the flux reaching the stator coils **216** is influenced by both the first gap spacing **210** and the second gap spacing **310**.

As described earlier, the axial gap generator **206** of FIG. **2**A can be mounted to a variety of surfaces. With respect to FIG. **2**A, the stator assembly **208** of the axial gap generator **206** is shown as mounted to a fixed surface, such as a housing or other structure at a known position. However, in some implementations, the stator assembly **208** can be mounted, partially or completely, on a movable support structure that is configured to move all or a portion of the stator assembly **208** parallel to the longitudinal axis A-A based at least in part on a physical property of an environment about the movable support structure. The movable support structure can move in response to a physical property and change the gap spacing **210** such that the voltage signal output from the axial gap generator **206** can be used to measure the physical property. The movable support structure can move the stator assembly **208** a displacement equal to the entirety of the size of the gap spacing **210**; however, the displacement of the stator assembly **208** need not be that large to effect a noticeable gap spacing change through the voltage signal output. For example, the movable support structure can move the stator assembly **208** and change the gap spacing **210** by 20% or less, while still being effective in that the voltage signal output can adequately represent the axial gap spacing **210** and its size changes relative to an initial spacing size.

For example, FIG. **4**A is a schematic cross-sectional side view of an example measurement tool **400** adjacent to the rotor **202** of FIG. 2A, where the example measurement tool **400** is like the measurement tool **200** of FIG. 2A except the stator assembly **208** is mounted to a movable support structure **402**. In particular, the movable support structure **402** attaches to the stator assembly **208** on a first side of the movable support structure **402**, and attaches to a support surface on a second side of the movable support structure **402** opposite the first side. The support surface can be a fixed structure, such as the housing of the measurement tool **400** or another fixed device with a known axial position along the longitudinal axis A-A. As the movable support structure **402** moves (e.g., flexes, expands, or contracts) in a direction parallel to the longitudinal axis A-A in response to a physical property (e.g., pressure, temperature, or other) of the environment around the movable support structure **402**, the position of the stator assembly **208** changes, thus changing the size of the gap spacing **210** and ultimately changing the voltage signal output of the axial gap generator **206**. Since the voltage signal output from the axial gap generator **206** depends at least partially on the operating speed of the rotor **202** and the axial position of the rotor, the voltage signal output is filtered to compensate for the operating speed and the axial position. In some implementations, the controller **222** performs this filtering to determine a measurement of the physical property that the movable support structure **402** is sensitive to.

The movable support structure **402** can take a variety of forms, and can include a flexible material, expandable material, compressible material, and/or other materials that allow relative movement between a first end of the movable support structure **402** and a second, opposite end of the movable support structure **402**. For example, the example measurement tool **400** of FIG. **4**A shows the movable support structure **402** as including a diaphragm **404**, or a bladder. The diaphragm **404** is sensitive to pressure, and can move (e.g., expand or contract) in a direction parallel to the longitudinal axis A-A when a pressure internal to the diaphragm **404** is different from an external pressure external to the diaphragm **404**. The diaphragm **404** has an initial internal pressure at a reference state. As the external pressure changes, the diaphragm **404** compresses or expands until the internal pressure within the diaphragm **404** matches the external pressure. For example, if an initial internal pressure of the diaphragm **404** is 15 psi and the external pressure increases to 100 psi (e.g., during operation of the rotor **202**), the diaphragm **404** compresses until the internal pressure is 100 psi to match the external pressure. In this example, a compression of the diaphragm **404** increases the size of the gap spacing **210**, thus changing the voltage signal output of the axial gap generator **206**. In another example, as an external pressure decreases below a first internal pressure of the diaphragm **404**, the diaphragm **404** expands until the internal pressure substantially or exactly matches the external pressure. This example expansion of the diaphragm **404** decreases the size of the gap spacing **210**, thus changing the voltage signal output of the axial gap generator **206**.

While FIG. **4**A shows the movable support structure **402** as attached to a side of the stator assembly **208** opposite the rotor **202**, the shape and location of the movable support structure **402** can be different. In some implementations, the movable support structure **402** can be attached to the side of the stator assembly **208** adjacent to the rotor **202**. For example, the stator back support **212** can extend radially outward such that the movable support structure **402** attaches to the rotor back structure **212** and extends in the second direction **314** to further attach to a fixed surface, such as a portion of a housing.

The movable support structure **402** of FIG. **4**A is shown as a ring-shaped diaphragm **404** that attaches to the stator assembly **208** at a radially outward portion of the stator back structure **214**. However, the movable support structure **402** can include a single movable support structure **402** attaching to all or a portion of the stator back structure **212**, can include one or more movable support structures **402** dispersed about the stator assembly **208**, or can take another form.

In some examples, the movable support structure **402** includes a temperature responsive material. FIG. **4**B shows an example measurement tool **410** similar to the example measurement tool **400** of FIG. **4**A, except the movable support structure **402** includes a temperature responsive material **412**. The temperature responsive material **412** is sensitive to temperature, and can move (e.g., expand or contract) in a direction parallel to the longitudinal axis A-A when a temperature of the environment surrounding the temperature sensitive material **412** changes.

The temperature sensitive material **412** has an initial position at an initial reference state, and expands or contracts with the temperature of the environment surrounding the temperature responsive material **412**. The temperature responsive material **412** can take a variety of forms. For example, the temperature responsive material **412** can include a thermoplastic, acrylic, Teflon™, a combination of these, or another material sensitive to temperature. The temperature responsive material **412** is more responsive to temperature than the surrounding materials of the stator assembly **208** and/or rotor **202**, for example such that the temperature responsive material **412** sufficiently displaces the stator assembly **208** a noticeable amount to effect a change in voltage output. In some instances, the temperature responsive material **412** can expand or contract at a rate significantly greater than two times the rate of surrounding material of the stator assembly **208**. The stator assembly **208** can have a reference axial position with a corresponding reference temperature of the temperature responsive material **412**, where a temperature of the environment greater than or less than the reference temperature causes the temperature responsive material **412** to expand or contract along a direction parallel to the longitudinal axis, changing a size of the gap spacing **210** and subsequently changing the voltage signal output of the axial gap generator **206**. For example, at a first reference temperature of 20° Celsius of the temperature responsive material **412**, the axial position of the stator assembly **208** can be at a reference, neutral position that produces a reference voltage signal output. When the temperature of the environment surrounding the temperature responsive material **412** changes, such as increases to 200° Celsius, an expansion rate of the temperature responsive material **412** moves the stator assembly **208** relative to the rotor **202** to reduce the gap spacing **210**, resulting in a higher voltage signal output. The increased voltage signal output can then be used to determine the effective temperature of the temperature responsive material **412**, the stator assembly **208**, itself, and/or the environment surrounding the temperature responsive material **412**.

All or a portion of the stator back structure **212** can attach to the movable support structure **402** to allow one or more or all of the stator coils **216** to move with the movable support structure **402** and subsequently change a gap spacing between the respective stator coils **216** and the rotor **202**.

In some instances, a first portion of the stator coils **216** can be configured to move independently from a second portion of the stator coils **216**, effectively functioning as two axial gap generators that present two different voltage signal outputs. For example, the movable support structure **402** can include two or more separate structures, each of the structures corresponding to a subset of the stator coils **216** and configured to move independently of each other. Each separate structure of the movable support structure **402** can attach to a respective set of the stator coils **216**. FIG. **4**C is a schematic cross-sectional side view of an example measurement tool **420** similar to the example measurement tool **400** of FIG. **4**A, except the movable support structure **402** includes a diaphragm **422** corresponding to a first subset of the stator coils **216** and a temperature responsive material **424** corresponding to a second subset of the stator coils **216**. The diaphragm **422** can be like the diaphragm **404** of FIG. **4**A, and the temperature responsive material **424** can be like the temperature responsive material **412** of FIG. **4**B. The measurement tool **420** incorporates both the diaphragm **422** and the temperature responsive material **424** such that the stator assembly **208** is configured to provide voltage signal output reflective of the pressure and/or temperature of the environment surrounding the stator assembly **208**.

In some implementations, a subset of the stator coils **216** is mounted on a longitudinally-sliding portion of the stator back structure **212**, for example, such that the subset of stator coils **216** longitudinally moves along with the movable support structure **402** to adjust a gap spacing between the rotor **202** and the subset of stator coils **216**. For example, FIG. **4**C shows the first subset of stator coils **216** mounted on a first longitudinally sliding portion **436** of the stator back structure **212** and the second subset of stator coils **216** mounted on a second longitudinally sliding portion **438** of the stator back structure **212**. The first subset of stator coils **216** moves with the axial movement of the diaphragm **422** to create a first gap spacing **210'**, and the second set of stator coils **216** moves with the axial movement of the temperature responsive material **424** to create a second gap spacing **210"**.

The longitudinally sliding portions **436** and **438** are connected to a fixed central portion of the stator back structure **212** with a sliding or guided support that allows longitudinal movement of the sliding portions **436** and **438**. For example, the longitudinal sliding portions **436** and **438** can each attach to the stator back structure **212** with a T-shaped pin and slot connection, where a T-shaped pin on the sliding portion or on the fixed portion of the stator back structure **212** slidably fits within a corresponding T-shaped slot in the other of the fixed portion of the stator back structure **212** or the sliding portion. This T-shaped pin-and-slot connection allows guided movement of the sliding portion **436** and/or sliding portion **438** in an axial direction (i.e., parallel to longitudinal axis A-A) while fixing the sliding portion **436** and/or sliding portion **438** in a radial direction perpendicular to the axial direction. This arrangement allows the stator coils **216** mounted on the respective sliding portions to maintain a radial position with respect to the rotor **202** while allowing longitudinal movement of the stator coils **216** to affect the gap spacing and corresponding voltage signal output. In some examples, one or more of the sliding portions **436** and/or **438** can attach to the stator back structure **212** with a flexible web interface. For example, FIG. **4**D is a schematic cross-sectional side view of an example measurement tool **420'** incorporating a flexible web interface **440**. The example measurement tool **420'** is the same as the example measurement tool **420** of FIG. **4**C, except the measurement tool **420'** includes the flexible web interface **440** between the stator back structure **212** and the respective longitudinal sliding portions **436** and **438**. As shown in FIG. **4**D, the longitudinal portions **436** and **438** can each attach to the stator back structure **212** with the flexible web interface **440** (e.g., made up of a plurality of axially spaced thin layers of material extending circumferentially from the stator back structure **212**), where the flexible web interface **440** connects to the respective longitudinally sliding portion **436** or **438** on a first end of the flexible web interface **440** and to the stator back structure **212** on a second, opposite end of the flexible web interface **440**. This flexible web interface **440** allows movement, by deflection of the web, of the sliding portion **436** and/or sliding portion **438** in an axial direction (i.e., parallel to longitudinal axis A-A) while holding the sliding portion **436** and/or sliding portion **438** in a radial direction perpendicular to the axial direction. This arrangement allows the stator coils **216** mounted on the respective sliding portions to maintain a radial position with respect to the rotor **202** while allowing longitudinal movement of the stator coils **216** to affect the gap spacing and corresponding voltage signal output.

FIGS. **4**C and **4**D show the measurement tool **420** or **420'** with the movable support structure **402** as including a diaphragm **422** and a temperature responsive material **424** distributed on opposite sides of the stator assembly **208**. The number, type, and position of structures within the movable support structure **402** can be different. In some implementations, the stator assembly **208** includes a subset of stator coils intended to be fixed to a housing or device of the measurement tool (e.g., like the stator coils **216** of FIG. **2**A). For example, a measurement tool can include a stator assembly with a first stator portion, a second stator portion, and a third stator portion, where each stator portion represents its own axial gap generator configured to measure a gap spacing between the rotor and the respective stator portions. Each stator portion can incorporate features from the position-sensitive, pressure-sensitive, and temperature-sensitive stator assembly configurations from the measurement tools of FIGS. **2**A-**4**D. In some examples, the first stator portion can be fixed to a housing, device, or other fixed structure with a known longitudinal position, where the first stator portion measures a first axial gap between the first stator portion and the rotor to generate a first voltage signal reflective of an axial position of the rotor. The second stator portion can be fixed to a pressure-sensitive movable support structure (e.g., diaphragm), where the second stator portion measures a second axial gap between the second stator portion and the rotor to generator a second voltage signal reflective of a pressure of the environment about the second stator portion. The third stator portion can be fixed to a temperature-sensitive movable support structure (e.g., a temperature-responsive material), where the third stator portion measures a third axial gap between the third stator portion and the rotor to generate a third voltage signal reflective of a temperature of the environment about the third stator portion. The stator assembly is split into three effective stator structures working off the same rotor to generate three voltage signals that are functions of respective gap spacings between the rotor and the respective stator structures, and a controller (e.g., controller **222**) can receive these three voltage signals to determine one or more or all of a longitudinal position of the rotor, a pressure about the rotor and/or stator assembly, and a temperature about the rotor and/or stator assembly. While the example stator assembly is described above as having three axial gap generators, a different number of stator structures, or axial gap generators, can be implemented.

While FIGS. **2**A to **4**B show one or two generator assemblies adjacent a rotor element, a different number of generator assemblies and/or rotor elements can be utilized. For example, multiple generator assemblies with multiple rotors and/or rotor elements (e.g., rotor poles) can be incorporated into a single tool or multiple tools. For example, a downhole-type tool with a single shaft can incorporate one, two, three, or more axial gap generator assemblies and one, two, three, or more rotor poles on a single shaft of the downhole-type tool. Multiple generator assemblies can be incorporated for reliability, redundancy in downhole and/or remote measurements, or other benefits.

As described earlier, the downhole-type tool **136** with the measurement tool **138** can take various forms, such as the downhole artificial lift system **124** of FIG. **1**. FIG. **5** is a half side cross-sectional view of the example downhole-type artificial lift system **124** of FIG. **1**. Referring to both FIGS. **1** and **5**, the example downhole-type artificial lift system **124** includes a fluid-end **500**, an electric machine **502**, and a thrust bearing module **504**. The electric machine **502**, the thrust bearing module **504**, and the fluid-end **500** are all coupled together on a central shaft **506** or rotor, but the central shaft **506** can instead be segmented, for example, separated into multiple rotor sections joined at longitudinal ends of each section with a coupling or other structure, described later. The artificial lift system **124** can incorporate one or more measurement tools, such as one or more of the measurement tools (**200**, **300**, **400**, **410**, **420**, **420'**) of FIGS. **2**A-**4**D, to interact with the central rotor **506** and measure an axial position of the rotor, an environmental temperature, and/or an environmental pressure. For example, FIG. **5** shows a first measurement tool **508** at a downhole end of the central rotor **506** within the electric machine **502**, a second measurement tool **510** proximate to the central rotor **506** at the thrust bearing module **504**, and a third measurement tool **512** proximate to the central rotor **506** at the fluid-end **500**. Each of the first measurement tool **508**, the second measurement tool **510**, and the third measurement tool **512** can be used to measure one or more of an axial position of the central rotor **506**, a temperature of an environment surrounding the respective measurement tool, and/or a pressure of the environment surrounding the respective measurement tool. While FIG. **5** shows the artificial lift system **124** as incorporating three measurement tools, the artificial lift system **124** can include a different number of measurement tools (e.g., 1, 2, 4, or more) positioned at any position along the central rotor **506**.

In the context of this disclosure, an uphole end or direction is an end nearer or moving in a direction towards the terranean surface **106**. A downhole end or direction is an end nearer of moving in a direction away from the terranean surface **106**. A coupling **514** is positioned at an uphole end of the fluid-end **500**. The coupling **514** can be of a type used for a wireline connection, a tubing connection, or any other connection configured to support the weight of the downhole-type artificial lift system. The coupling **514** can include a standard attachment method to attach the downhole-type artificial lift system to a support system. For example, a threaded interface can be used for a sucker rod, or a set of bolts can be used to attach two flanges together for production tubing.

In the example artificial lift system **124** of FIG. **5**, the electric machine **502** is positioned downhole of the fluid-end **500**, and the thrust bearing module **504** residing between the electric machine **502** and the fluid-end **500**. In some instances, the fluid-end **500**, the thrust bearing module **504**, and the electric machine **502** can be assembled in a different order. For example, the thrust bearing module **504** can be positioned downhole of the electric machine **502** or uphole of the fluid-end **500**.

In FIG. **2**, the central shaft **506** is made up of multiple sub-sections coupled together: a fluid rotor **506***a*, a thrust bearing rotor **506***b*, and an electric rotor **506***c*. Each sub-section is joined together by a coupling **516**. The coupling **516** can be a bellows, quill, diaphragm, or other coupling type that provides axial stiffness and radial compliance. In certain instances, the coupling **516** can allow for angular misalignment (e.g., misalignment of 0.30-2.0 degrees), and a lateral misalignment (e.g., misalignment of 0.01 inches). Variation in thermal growth can be designed to be accepted in the compressor and motor clearances, though the coupling **516** can tolerate some degree of axial misalignment (e.g., axial misalignment of about 0.03 inches). Larger and smaller alignment tolerances can be achieved with different coupling configurations and sizes, specific to the application needs. In some implementations, the central shaft **506** can include a single, unitary shaft that runs through the fluid-end **500**, the thrust bearing module **504**, and the electric machine **502**.

The fluid end **500** directs fluid flow through the fluid end **500**, or is driven by fluid flowing through the fluid end **500** based on a pressure differential across the fluid end **500**. The electric machine **502** is configured to rotatably drive the fluid end **500** or be driven to generate electricity by the fluid-end **500**. The central shaft **506** is levitated and axially supported by one or more active magnetic thrust bearing assemblies **518** located in the thrust bearing module **504**. One or more passive magnetic radial bearing assemblies **522** radially levitate and support the central shaft **506**. While one of each electric machine **502**, thrust bearing module **504**, and fluid-end **500** modules are shown, more than one of each or all are practical in this configuration, thus allowing for additional motor power, additional thrust load support, and additional flow or pressure capacity to be added independently of each other to best produce the specific well performance. In addition, while the order of electric machine **502**, thrust bearing module **504**, and fluid-end **500** module from downhole to uphole is shown, each module functions independently and can be placed in other orders that best suit the operation and integration of each module. Additionally, while a fluid-end **500** is shown, this can include a blower, a compressor, a liquid pump, a multiphase pump, or a combination thereof that best suits the fluids and conditions of the well to maximize well performance. In addition, the use of passive magnetic radial bearing assemblies **522** and active magnetic thrust bearing assemblies **518** can be seen as one example of such an implementation of magnetic bearings, where active radial bearings and/or passive thrust bearings can be used instead of or in addition to, in any case to enhance the downhole system performance.

In some implementations, the fluid-end **500** includes an inlet **526** to receive a fluid (e.g., gas) at the first pressure downhole of the fluid-end **500** and an outlet **528** to output the fluid at the second, higher pressure uphole of the fluid-end **500**. A cylindrical outer housing **530** houses an impeller **532** in fluid communication with the inlet **526** to receive a production fluid from the wellbore **104** at the first pressure downhole of the fluid-end **500** and to drive the production fluid to the outlet **528** at the second, higher pressure uphole of the fluid-end **500**. The impeller **532** is attached to or integrated with a fluid end rotor section **506***a* of the central rotor **506**, and configured to rotate with the central rotor **506**, for example, to drive or be driven by the central rotor **506**. The third measurement tool **512**, shown as positioned adjacent to the uphole end of the fluid end rotor section **506***a*, can act as a position sensor, temperature sensor, and/or pressure sensor, outputting one or more voltage signals representative of the axial position of the fluid end rotor section **506***a*, a temperature, and/or a pressure of an environment within the fluid end **500**. In the illustrated implementation, the fluid-end **500** is coupled to an uphole end of the thrust bearing module **504** by the coupling **516** and a coupling housing **517**.

As previously described, the downhole-type artificial lift system **124** moves the fluid from the downhole inlet **526** at the first pressure to the uphole outlet **528** at the second, higher pressure. This pressure differential promotes the fluid flow to move uphole of the artificial lift system **124**, for example, at a higher flow rate compared to a flow rate in a wellbore without a downhole-type artificial lift system. The fluid-end **500** can operate at a variety of speeds, for example, where operating at higher speeds increases fluid flow, and operating at lower speeds reduces fluid flow. In some instances, the impeller **532** of the fluid-end **500** can operate at speeds up to 120,000 revolutions per minute (rpm). In some instances, the impeller **532** of the fluid-end **500** can be run at lower speeds (e.g., 40,000 rpm, or other).

FIG. **5** shows the electric machine **502** as coupled to a downhole end of the thrust bearing module **504**. The electric machine **502** is configured to either drive the central rotor **506** or be driven by the central rotor **506** to generate electricity. In some implementations, the electric rotor section **506***c* includes a permanent magnet rotor that is axially levitated and supported by the thrust bearing module **504**. The permanent magnet rotor **506***c* is coupled to the thrust bearing rotor **506***b* by a coupling **516**. An electric stator **534** surrounds the permanent magnetic rotor **506***c*. The electric stator **534** includes electric coils **536**. In some implementations, a passive magnetic radial bearing structure **522** can support and levitate the permanent magnet rotor **506***c* to the electric stator **534**. As the permanent magnet rotor **506***c* is axially supported by the thrust bearing module **504**, no thrust bearing is needed within the electric machine **502**. The first measurement tool **508** positioned adjacent to the downhole end of the permanent magnet rotor **506***c* can act as a position sensor, temperature sensor, and/or pressure sensor, outputting one or more voltage signals representative of the axial position of the permanent magnet rotor **506***c*, a temperature, and/or a pressure of an environment within the electric machine **502**. The stator **534** can be canned using a metallic or non-metallic sleeve on the inner diameter of the stator **534** to separate an environment within the electric machine **502** with the environment about (e.g., surrounding) the electric machine **502**. In some examples, the measurement tool **508** can also be canned within the sleeve on the inner diameter of the stator **534**, or the measurement tool **508** may not be canned. For example, in some instances, the canning sleeve can pass through the axial gap between the longitudinal end of the rotor **506***c* and the stator assembly of the measurement tool **508**, where the canning sleeve does not interfere with the axial gap sensing of the axial gap generator of the measurement tool **508**. In certain instances, the measurement tool **508** can be used to determine the axial position of the rotor, a pressure within the electric machine **502**, a pressure of the environment (e.g., fluid) about the electric machine **502**, a temperature within the electric machine **502**, and/or a temperature of the environment (e.g., fluid) about the electric machine **502**. The can can be sealed, by welding for example, at each end and supported from any well pressure by the stator and/or potting behind the sleeve to insure it does not deform during operation. Multiple electric machines **502** can be connected in series to produce more power to drive the central rotor **506**, if needed.

The electric machine **502** is controlled by a high frequency variable speed drive (e.g., VSD **140** of FIG. **1**), for example, at the surface of the well. Variable frequency or speed allows the electric machine **502** to rotate the device (e.g., rotor **506**) at a speed optimal for well production. It also allows for one electric machine drive to be used at many well sites where performance in speed and power vary. While sensored drives could be used, bringing sensor signals to the surface over long distances presents many challenges, including cables and connectors in addition to having the actual sensor and their associated electronics installed in the system. The downhole-type artificial lift system **124** uses a sensor-less VSD capable of long distance (>300 meters) to control the electric machine **502**. This sensor-less VSD monitors the speed of the electric machine **502** and is able to maintain speed or torque control of the electric machine **502** to ensure it operates as desired. The VSD is also capable of interpreting the machine parameters and/or voltage output signals from the measurement tool **508** to provide operating data on motor temperature and fluid properties, such as density, for example.

Cables connect the topside VSD to the downhole electric machine **502**, transmitting the low voltage (e.g., <600 VAC) or medium voltage (e.g., <10,000 VAC) from the VSD to the electric machine **502**. For longer distances, higher voltage is desired to reduce current losses in the cable and reduce cable size. Reductions in cable size reduce cable cost and cable weight, though may require higher class of electrical insulation on the cable.

The thrust bearing module **504** provides bearing support for the central shaft **506**. FIG. **6**A is a schematic side half cross-sectional view of the example thrust bearing module **504** of FIG. **5**. Referring to both FIGS. **5** and **6**, the thrust bearing module **504** includes one or more active magnetic thrust bearings **518** that support the central rotor **506**, in particular the bearing rotor section **506***b* of the central rotor **506**, to a surrounding stator **540**. The active magnetic thrust bearing **518** is configured to levitate and support the central rotor **506** axially within an outer housing **542** (surrounding stator **540**). Passive radial bearings **522** are configured to levitate and support a central rotor **506** radially within the outer housing **542**.

In some implementations, an active damping circuit **544** can be included with the passive radial bearing **522**. The active damping circuit **544** uses a coil to sense rotor radial motion and provide a current in size and frequency relative to this motion to a control board. The control board amplifies this signal and adjusts the relative polarity/phase to feed it back to a damping coil that reacts against the rotor field to resist the motion, thus damping out the motion. No radial position sensors or controller is required for the passive radial bearing operation. The active damping circuit **544** is able to adjust the magnetic field sufficiently enough to reduce vibration, but does not have the power to significantly affect the lifting or support characteristics of the bearing. This approach can be used for a radial axis or a longitudinal axis, where a sense coil output sensing axial motion is amplified and fed to a damping coil to react against the rotor field to resist motion. In some implementations described later, the thrust bearing module **504** can include an axial gap generator assembly separate from or incorporated into the active damping circuit **544** that generates power when the axial gap changes and thus powers a control coil to increase a levitating or centering force. Thus, it doesn't need a sensor or an outside power source/controller.

The active magnetic thrust bearing assembly **518** and the passive magnetic radial bearing assembly **522** fully support the central shaft **506** with one or more electromagnetic fields. That is, the central shaft **506** is not physically coupled to the outer housing **542** during normal operation; there is no physical connection between the central shaft **506** and the outer housing **542**. In other words, the shaft **506** is spaced apart from the housing **542** and any associated mechanism connected to the housing **542**, where a gap exists between the central shaft **506** and the housing **542**.

In some instances, position sensors are required for the active magnetic bearing, such as for the thrust bearings **518**. Position sensors can be located within the thrust bearing module **504**, within the fluid end **500**, or in any other location along the rotor **506**, for example, a location intended to a central point of axial position control. The second measurement tool **510** can be used to provide an axial position measurement for the rotor **506**, along with temperature and/or pressure measurements within the thrust bearing module **504**. The measurement tool **510** can be isolated from the wellbore environment or be exposed to the wellbore environment depending on the construction of the thrust bearing module **504**.

The second measurement tool **510** includes a position-sensitive axial gap generator, as described earlier, that can produce a voltage signal as the rotor **506** rotates proportional to, or as a function of, the axial gap between the axial gap generator and the rotor **506** to determine axial position of the central rotor **506**. This offers a high voltage output that can be transmitted over long distances to minimize line drop and noise issues. For example, the axial gap generator of the second measurement tool **510** can tap into a communication line or another line extending topside (e.g., to the VSD **140**) to provide its voltage output to a tophole device (e.g., the magnetic bearing controller **150**) that interprets the voltage output into an axial position measurement.

The thrust bearing module **504** compensates for axial loads and holds, or re-centers, the axial position of the rotor **506** by applying force to the rotor **506** to maintain position or force the rotor **506** to a center, or neutral, position. For example, as loads are developed on the rotor **506** from the act of compressing or pumping fluids, the thrust bearing controller **150** senses position movement of the rotor **506** from a target set point. The controller **150** then increases the current to control coils **546** of the thrust bearing assembly **518**, where the current is converted to an axial force on the rotor **506**. This force can be determined based at least in part on the amount of displacement sensed and the rate of change in motion using a control approach set by the controller **150**. The thrust bearing **518** with controller **150** is thus able to compensate for forces on the rotor **506** and apply corresponding off-setting axial forces to keep the rotor in an axially centered position. While a permanent magnet on the rotor configuration is shown, various configuration of thrust bearing could be applied, including all electric or alternative permanent magnet configurations.

As illustrated in FIGS. **5** and **6**A, the thrust bearing module **504** allows for non-magnetic spacers **548** to be used at the rotor outer diameter for setting stator axial position and for locking the split stator assemblies **550** of the thrust bearing assembly **518**. Opposite polarity permanent magnets **552** are used on the rotor **506***b* to allow for coil wrapping of one or more back-to-back stator "C" shaped cores **546** to reduce overall bearing size and make assembly possible in split stator halves (i.e. both use the same coil). The outer housing **542**, limited by the well installation casing size and flow path requirements, limits thrust bearing outer diameter, where the rotor outer diameter is further limited by the stator spacer and adequate clearance for rotor radial motion during operation and transport, and radial rotor growth due to high speed operation. In the illustrated implementation, the stator poles **554** of the thrust bearing assembly **518** are radially offset from the rotor poles **556** on the rotor **506**. With the restricted rotor outer diameter limiting the rotor pole size, the stator pole offset increases the cross section of the stator poles **554**, which increases the capacity of the thrust bearing **518**, increasing bearing capacity without increasing overall bearing size.

Illustrated in FIG. **6**B is an example "C" shaped core **546** used in the stator **550**. The polarity for these coils **546** as it applies to each opposite pole face is opposite of one another. Each back to back "C" shaped core **546** is split in half to form two 180 degree assemblies. The coils **546** in each of these 180 degree assemblies are wrapped from one side to the other, and results in opposite coil polarity on each side of the "C" shaped core **546**. This, in conjunction with the permanent magnets **552** on the rotor **506***b* having opposite polarity to the adjacent magnet, works to minimize size and simplify integration (coils that are split do not need to be routed to the outer diameter where they take up additional room and do not aid in generating bearing force).

The illustrated implementation (FIG. **6**A) shows a three bearing module **518** with a first thrust bearing **518***a*, a second thrust bearing **518***b*, and a third thrust bearing **518***c*. The stator pole on the third thrust bearing **518***c* is missing in the arrangement shown, where this is to be the downhole side of the module. Since the thrust load is generally in a downhole direction as the system pushes fluid uphole, this arrangement of leaving the bottom stator pole provides a passive force in the uphole direction. That is, with no current, the module will lift the rotor **506***b* (and anything coupled to the rotor **506***b*) in an uphole direction. Further lift can be imparted on the rotor with coil current in one direction, and lift can be reduced with coil current in the opposite direction. The number of thrust bearings in a module can be one or more, depending on size, integration, rotodynamics, and other design considerations.

The bearing module **504** includes a rotor outer pole **556***a*. The rotor outer pole **556***a* is a magnetic steel pole that is magnetically acted upon by the stator pole **554** to produce force on the rotor **506***b*. The rotor outer pole **556***a* acts to conduct a permanent magnet field and a coil generated magnetic field and acts as the primary containment of the permanent magnet **558** onto the rotor for high speed operation. In some implementations the rotor outer pole **556***a* is secured with an interference fit on an inner diameter of the rotor outer pole **556***a* to the permanent magnet ring **558**.

A rotor inner pole **556***b* is a magnetic steel pole that is magnetically acted upon by the stator pole **554** to produce force on the rotor **506***b*. The rotor inner pole **556***b* acts to conduct the permanent magnet field and the coil generated magnetic field. The rotor inner pole **556***b* is the primary connection point to the central shaft **506** (i.e., rotor **506***b*) with which the thrust bearing forces are applied to the shaft **506**.

The radially magnetized permanent magnet ring **558** is a permanent magnet material that provides magnetic field that the thrust bearing **518** uses to distribute to stator poles **554** on each side of the rotor **506***b*, thus energizing each gap between rotor pole and stator pole. The permanent magnet field provides roughly half of the maximum field designed for the stator poles **554** and rotor poles **556***a* and **556***b*, where this level allows for linear current load response from the bearing. The permanent magnet ring **558** is radially magnetized to provide a uniform polarity field to the outer poles and inner poles. With the use of multiple thrust bearings **518**, the polarity of these rotor permanent magnets **558** changes from one to the next to allow for opposite coil polarity in double stator poles.

A rotor seal can **560***a* is a ring that covers the permanent magnet **558** sides and is welded or otherwise sealed to the metal outer and inner poles to prevent process fluids from contacting the permanent magnet and degrading performance. The cans **560***a* can be metallic, and nonmagnetic, but could also be made of a non-metallic material, such as Peek or ceramic.

The thrust bearing stator pole **554** is a stator pole that includes a magnetic steel material that conducts the permanent magnet flux and electromagnet coil flux for energizing the pole air gaps that result in forces on the rotor **506***b*. The thrust bearing stator poles **554** are secured to the housing to transmit forces relative to the outer housing **542**.

The thrust bearing coil **546** is an electromagnet coil that is a wound coil with electronic insulation to take currents from the magnetic bearing controller and convert these to magnetic field in the thrust bearing **518**. In some implementations, the thrust bearing coil conductors **546** can be made of copper or a copper alloy.

The thrust bearing stator seal can **560***b* is a ring that covers the electromagnet coil **546** sides and is welded or otherwise sealed to the metal outer and inner poles to prevent process fluids from contacting the electromagnet coil and affecting performance. The cans **560***b* can be metallic, and nonmagnetic, but could also be made of a non-metallic material, such as Peek or ceramic.

The stator pole spacer **548** is a spacer that includes non-magnetic steel pieces and is used to set the relative position of two stators or a stator and housing to locate the stator poles in relation to the housing **542**.

A double stator pole is split in two halves for assembly (a single half is shown in detail in FIG. **6**B). These stator poles include two halves that use two coils. The coils wrap 180° on one side and then are routed to the other side where they wrap 180° back and route back to where they started to form a complete loop. This coil winding, along with polarizing the opposite rotor magnets for each subsequent rotor, allows for utilizing the complete coil loop for a split stator pole. As such the two poles are combined for minimum space necessary.

Different configurations of the thrust bearings can be used to achieve the same or similar results. In some implementations, the thrust bearings can include electromagnetic-coil based bearings, other permanent magnet based thrust bearings, and/or any other magnetic bearing assemblies configured to apply thrust forces on a rotor.

In some implementations, the thrust bearing module **504** incorporates one or more axial gap generators that provide power to the magnetic bearing system, particularly the magnetic thrust bearing actuators **518**. An axial gap generator assembly separate from or incorporated into damping circuit **544** can generate power when an axial gap increases or decreases, and thus powers a control coil to increase or decrease force acting on the rotor by the magnetic bearing system, for example, in an uphole or downhole direction. The axial gap generator assembly does not need a sensor, controller, or amplifier to supply power to the active magnetic bearing system, but some implementations can use a controller and amplifier for enhanced performance and/or control. The axial gap generator(s) is reactive to longitudinal displacement of the rotor **506***c*. For example, an axial gap generator positioned adjacent the rotor **506***c* can generate an amount of power as a function of a gap spacing between the rotor **506***c* and the axial gap generator. The axial gap generator can provide the amount of power to one or more coils **546** of the magnetic thrust bearing actuator **518** that imparts an axial force, or thrust force, on the rotor **506***c*. In some implementations, an axial gap generator can generate an increased amount of power in response to movement of the rotor **506***c* in a first longitudinal direction (e.g., reducing a size of the gap spacing), and supply the increased amount of power to a control coil **546** of the magnetic thrust bearing actuator **518** to apply a force on the rotor **506***c* in a direction opposing the movement of the rotor **506***c*, for example, in a second direction opposite the first direction. In some examples, an axial gap generator with a stator assembly on both longitudinal ends of the rotor that are sensitive to two gap spacings can provide a balanced power output to a magnetic bearing system such that axial displacement of a rotor in a first direction or a second, opposite direction (e.g., uphole or downhole directions) causes the axial gap generator to supply an amount of power to the magnetic bearing system, and the magnetic bearing actuator can then provide a force on the rotor in a direction that opposes the axial displacement of the rotor. In some instances, an axial gap generator with a stator assembly proximate to one end of the rotor is constructed using a single rotor (e.g., a radial protrusion of the rotor such that there are two longitudinal sides of the radial protrusion) with a stator on either longitudinal side of the rotor, where the stators are sensitive to two gap spacings and can provide a balanced power output to a magnetic bearing system such that axial displacement of the rotor in a first direction or a second, opposite direction (e.g., uphole or downhole directions) causes the axial gap generator to supply an amount of power to the magnetic bearing system, and the magnetic bearing actuator can then provide a force on the rotor in a direction that opposes the axial displacement of the rotor.

For example, FIG. **7** is a side cross-sectional view of an example thrust bearing module **700** that incorporates an axial gap generator assembly **702**. The example thrust bearing module **700** is the same as the thrust bearing module **504** of FIG. **6**A, except the thrust bearing module **700** includes the axial gap generator assembly **702** located adjacent to (e.g., close to, next to, or otherwise positioned to interact with) the rotor **506***c*. While the thrust bearing module **700** is shown as excluding the second measurement tool **510**, in some examples the thrust bearing module **700** can include the second measurement tool **510** in addition to or integral with the axial gap generator assembly **702**. The example thrust bearing module **700** of FIG. **7** shows the axial gap generator assembly **702** as adjacent to both longitudinal ends of the rotor **506***b*, but this positioning can be different. For example, the axial gap generator assembly **702** can be positioned adjacent to only one longitudinal end of the rotor **506***b*, or adjacent to one or more longitudinal sides of a radial protrusion of the rotor **506***b*, described in more detail later. The axial gap generator assembly **702** generates an amount of power based on a longitudinal location of the rotor **506***c* relative to the axial generator assembly **702**, and supplies that amount of power to the magnetic thrust bearing actuator **518**. The axial gap generator assembly **702** electrically connects to the thrust bearing actuator **518** such that movement of the rotor **506***c* in a first longitudinal direction (e.g., in an uphole direction or a downhole direction) causes the axial generator assembly **702** to generate an amount of power that is supplied to a control coil **546** of the thrust bearing actuator **518**, where the coil **546** imparts a force on the rotor **506***c* in a direction that opposes the movement of the rotor **506***c*, for example, in a second longitudinal direction opposite the first longitudinal direction. The axial gap generator assembly **702** acts as a passive, or reactive, generator that supplies an entirety of the power it generates to the thrust bearing actuator **518**, and does not require a controller or other processing device to control and transmit the amount of power to the bearing actuator **518** as a function of the axial position of the rotor **506***c* (e.g., the gap spacing between the axial gap generator and the rotor **506***c*). For example, all of the power generated by the axial gap generator assembly **702** is sent directly to the control coil(s) **546** of the thrust bearing assembly **518**. In the example shown in FIG. **7**, a rectifier between the axial gap generator assembly **702** and the control coils **546** converts an AC signal from the generator assembly **702** to DC signal to the control coils **546**, while maintaining all of the power output from the generator assembly **702** to the control coils **546** other than inherent minor losses in converting from AC to DC. While a rectifier, amplifier, or other intermediate device may be connected between the axial gap generator assembly **702** and the thrust bearing assembly **518**, there is no decrease in the amount of power from the axial generator assembly **702** to the thrust bearing actuator **518**, other than inherent minor losses.

FIG. **8**A is a partial schematic cross-sectional side view of the example axial gap generator assembly **702** of FIG. **7** positioned adjacent to the rotor **506***c*. The axial gap generator assembly **702** outputs an amount of power based on an axial position of the rotor **506***c*, for example, along the longitudinal axis A-A about which the rotor **506***c* is configured to rotate. The axial gap generator assembly **702** is a displacement based response system, where an axial offset of the rotor **506***c* from a neutral, center position causes an output imbalance from the axial generator assembly **702**, which is fed to the thrust bearing actuator assembly **518** that imparts a force on the rotor **506***c* based on the imbalance. The axial gap generator assembly **702** is self-controlling in that it does not require a controller or other external control circuit to operate, and operates as a passive device responsive to axial displacement of the rotor **506***c*. While the axial generator assembly **702** is shown and described as incorporated into the thrust bearing module **504** of FIG. **7**, the axial generator assembly **702** can be incorporated into a different rotating assembly with a different magnetic bearing assembly. In other words, the axial generator assembly **702** can engage with a rotating rotor of another rotating tool, and can provide a power output to a control coil of a different magnetic bearing assembly.

The axial gap generator assembly **702** includes a first stator assembly **704***a* that is sensitive to a first axial gap **706***a* between a first longitudinal end **708***a* of the rotor **506***c* and the first stator assembly **704***a*, and parallel to the longitudinal axis A-A, and includes a second stator assembly **704***b* that is sensitive to a second axial gap **706***b* between a second longitudinal end **708***b* of the rotor **506***c* and the second stator assembly **704***b*. Each of the first stator assembly **704***a* and the second stator assembly **704***b* can be similar to the stator assembly **208** of the axial gap generator **206** of FIGS. **2**A-**3**. For example, the stator assemblies **704***a* and **704***b* each have a stator back structure **712***a* and **712***b*, stator poles **714***a* and **714***b*, and stator coils **716***a* and **716***b* surrounding respective stator poles **714***a* and **714***b*, respectively. The axial gap generator assembly **702** generates the amount of power as a function of the first gap spacing **706***a* between the first stator assembly **704***a* and the rotor **506***c* and the second gap spacing **706***b* between the second stator assembly **704***b* and the rotor **506***c*. The rotor **506***c* is shown as having rotor poles **717** adjacent to the stator poles **714***a* and **714***b*. Each stator assembly **704***a* and **704***b* include a magnetic field source in the form of a field coil **718***a* and **718***b*, respectively, where the axial gap generator assembly **702** is an electromagnetic-type generator. The field coils **718***a* and **718***b* can be connected to a local power source or other power source to provide a current to the respective stator assemblies **704***a* and **704***b*. In some embodiments, the axial gap generator assembly **702** is a permanent magnet-type generator, where the field source includes a permanent magnet, for example, instead of the electromagnetic field coils **718***a* and/or **718***b*.

The gap spacings **706***a* and **706***b* are parallel to the longitudinal axis A-A. The size of the axial gap spacings **706***a* and **706***b* determines the power output of the axial gap generator assembly **702**. The axial gap generator assembly **706** varies the power output reflective of a variance in the gap spacings **706***a* and **706***b*, for example, in response to a displacement of the rotor **506***c* relative to the stator assemblies **704***a* and **704***b* and parallel to the longitudinal axis A-A. For example, when the rotor **506***c* moves with respect to the longitudinal axis A-A, the gap spacings **706***a* and **706***b* change, and a flux across each of the gap spacings **706***a* and **706***b* reaching the respective stator assemblies **704***a* and **704***b* changes; thus the first stator assembly **706***a* and the second stator assembly **706***b* produce a different power output signal as the gap spacings **706***a* and **706***b* vary. In some examples, the stator assemblies **704***a* and **704***b* are mounted to a housing of the thrust bearing module **504** or other fixed structure, while the rotor **506***c* is designed to longitudinally displace to some degree (for example, up to a size of the gap spacing **706***a* or gap spacing **706***b*) during operation.

The axial gap generator assembly **702** generates an amount of power (e.g., in the form of a voltage output) as a function of one or both of the gap spacings **706***a* and **706***b*. In the example assembly **702** of FIG. **8**A, the axial gap generator assembly **702** outputs a single power output signal reflective of the axial position of the rotor and as a function of both the first gap spacing **706***a* and the second gap spacing **706***b*. The first stator assembly **704***a* produces a first power output as a function of the first gap spacing **706***a*, and the second stator assembly **704***b* produces a second power output as a function of the second gap spacing **706***b*, and the first and second power outputs are combined into a single power output signal sent to the thrust bearing assembly **518**, and the first and second power outputs are out of phase such that a single power output signal can have a directional response (e.g., uphole or downhole force) when actuated at the thrust bearing actuator **518**. In some examples, the single power output from the axial generator assembly **702** is zero when the rotor is centered, where the first stator assembly **704***a* output and the second stator assembly **704***b* output cancel each other out when combined. As the rotor **506***c* axially moves in a first direction **720** or a second direction **722** opposite the first direction **720** and parallel to the longitudinal axis A-A, the polarity of the single output from the axial generator assembly **702** changes, thereby changing the net axial force on the rotor for an independently biased magnetic bearing actuator.

For example, referencing both the thrust bearing module **700** of FIG. **7** and the axial gap generator assembly **702** of FIG. **8**A, the actuator configuration is a permanent magnet that provides a bias field to the actuator. The output of both stator assemblies **704***a* and **704***b* of the axial gap generator assembly **702** can be combined, with the first stator assembly **704***a* (e.g., first generator) being 180 degrees out of phase with the second stator assembly **704***b* (e.g., second generator). When the axial gap spacings **706***a* and **706***b* at both generators is equal or the same, no net power is provided to the thrust actuator assembly **518**. For example, no force on the rotor **506***c* is desired to be applied to the rotor **506***c* since the rotor is centered. As the axial position of the rotor **506***c* changes one way or the other (e.g., in the first direction **720** or the second direction **722**), the power output balance (e.g., net-zero power) out of the generator assembly **702** changes, and power is either positive or negative depending on the displacement direction of the rotor **506***c* and direction of force desired to pull the rotor **506***c* in a direction opposite from the displacement. In some instances, this net power output of the generator assembly **702** can be accomplished with the rotor poles or stator windings being out of phase with each other, such that when the power output signals from the stator assemblies **704***a* and **704***b* are combined with each other, a net power output is realized. In certain instances, the net power output of the generator assembly **702** can be done in a rectifier circuit at a rectifier, where one stator assembly output is on the positive leg and the other stator assembly output is on the negative leg. When the power outputs from the stator assemblies are equal (e.g., at the center position of the rotor **506***c*), the net power output to the thrust bearing actuator assembly **518** is zero. Other methods of power generation from the stator assemblies are possible though, as described elsewhere in this disclosure.

The axial gap generator assembly **702** generates an amount of power (e.g., in the form of a voltage output) as a function of one or both of the gap spacings **706***a* and **706***b*. In the example assembly **702** of FIG. **8**A, the first stator assembly **704***a* and the second stator assembly **704***b* electrically connect to a thrust bearing actuator, such as the thrust bearing actuator assembly **518** of FIG. **7**, to provide a combined output for the biased thrust bearing actuator to act on the rotor **506***c*. In some implementations, the thrust bearing type can be different, such as thrust bearings configured without a bias field, and an axial gap generator assembly can provide a power output to these other configurations of a thrust bearing. For example, each stator assembly of an axial gap generator assembly can provide its own power output to a respective bearing coil, as opposed to a combined power output signal from multiple stator assemblies. FIG. **8**B is a partial schematic cross-sectional side view of an example axial gap generator assembly **702'** positioned adjacent to the rotor **506***c*. The axial gap generator assembly **702'** is the same as the axial gap generator **702** of FIG. **8**A, except the assembly **702'** connects to a different thrust bearing assembly type, particularly thrust bearing assembly **800**, which axially supports the rotor **506***c*. The axial gap generator **702'** is structurally similar to the axial gap generator **702** of FIG. **8**A, and is configured to output an amount of power based on the axial position of the rotor **506***c*. In the example assembly **702'** of FIG. **8**B, the first stator assembly **704***a* electrically connects to a first control coil **804***a* of a thrust bearing actuator **802** of the thrust bearing assembly **800**, and the second stator assembly **704***b* electrically connects to a second control coil **804***b* of the thrust bearing actuator **802**. The first stator assembly **704***a* is positioned on a downhole side of the rotor **506***c* while the first coil **804***a* of the thrust bearing actuator **802** is positioned on an uphole side of a rotor pole **806**. The second stator assembly **704***b* is positioned on an uphole side of the rotor **506***c* while the second coil **804***b* of the thrust bearing actuator **802** is positioned on a downhole side of the rotor pole **806**. As the rotor **506***c* rotates, the first stator assembly **704***a* supplies a first amount of power to the first coil **804***a*, and the second stator assembly **704***b* supplies a second amount of power to the second coil **804***b*, where the first coil **804***a* acts to provide a force on the rotor in a first axial direction and the second coil **804***b* acts to provide a force on the rotor in a second axial direction opposite the first direction. The first coil **804***a* and the second coil **804** impart a pulling force against the rotor **506***c*, in that a force by the first coil **804***a* is a force on the rotor **506***c* toward the first coil **804***a*, and a force by the second coil **804***b* is a force on the rotor **506***c* toward the second coil **804***b*. For example, in a center position of the rotor where the first axial gap **706***a* and the second axial gap **706***b* are the same size, the amount of power provided to the coils of the magnetic bearing actuator **802** results in a net zero force on the rotor **506***c* from the magnetic bearing actuator **802**. In other words, at the center position of the rotor, a non-zero force applied on the rotor **506***c* from the first coil **804***a* and a non-zero force applied on the rotor **506***c* from the second coil **804***b* is equal in magnitude and opposite in direction, so a net force on the rotor **506***c* is zero. As the rotor **506***c* moves axially, the gap spacings **706***a* and **706***b* change, and the first and second amounts of power from the stator assemblies **704***a* and **704***b* change, resulting in a non-zero net force on the rotor **506***c*. For example, as the rotor **506***c* moves in the first direction **720**, the first gap spacing **706***a* gets smaller and the second gap spacing **706***b* gets larger. The first stator assembly **704***a* provides an increase amount of power to the first coil **804***a* based on the smaller first gap spacing **706***a* as compared to the second stator assembly **704***b*, which provides a decreased amount of power to the second coil **804***b* based on the larger second gap spacing **706***b*. The force applied on the rotor **506***c* from the first coil **804***a* is larger than the force applied on the rotor **506***c* from the second coil **804***b*, resulting in a net force on the rotor in the second direction **722** opposite the first direction **720**, where the net force opposes the axial displacement of the rotor **506***c*. In some examples, as the rotor **506***c* moves in the second direction **722**, the first gap spacing **706***a* gets larger and the second gap spacing **706***b* gets smaller. The first stator assembly **704***a* provides a decreased amount of power to the first coil **804***a* based on the larger first gap spacing **706***a* as compared to the second stator assembly **704***b*, which provides an increased amount of power to the second coil **804***b* based on the smaller second gap spacing **706***b*. The force applied on the rotor **506***c* from the second coil **804***b* is larger than the force applied on the rotor **506***c* from the first coil **804***a*, resulting in a net force on the rotor in the first direction **720** opposite the second direction **722**, where the net force opposes the axial displacement of the rotor **506***c*.

While one version of the magnetic thrust bearing **802** is shown in FIG. **8**B, various other configurations of the thrust bearing can be used that can function in the same manner with an axial gap generator providing power that is dependent on rotor position and axial gap generator gap spacing.

While FIGS. **8**A and **8**B show the axial gap generator assemblies and respective stator assemblies positioned at longitudinal ends of the rotor **506***c*, the position of the axial gap generator assemblies and their respective stator assemblies can vary. The stator assemblies can be positioned anywhere along the longitudinal length of the rotor adjacent to a rotor element or rotor pole extending radially from the central axis A-A. For example, FIG. **8**C is a partial schematic cross-sectional side view of an example axial gap generator assembly **702"** positioned adjacent to the rotor **506***c*. The axial gap generator assembly **702"** is the same as the axial gap generator **702** of FIG. **8**A, except the second stator assembly **704***b***"** is positioned on an opposite longitudinal side of the rotor element **810** opposite from the first stator assembly **704***a*, instead of on an opposite longitudinal end of the rotor **506***c*. The rotor element **810** includes rotor poles **717** extending in both longitudinal directions and positioned adjacent to (but spaced apart from) respective stator coils. The second stator assembly **704***b*" of FIG. **8**C is positioned on an uphole side **708***b* of the rotor element **810** at the downhole end of the rotor **506***c*, where the downhole end of the rotor **506***c* includes the radially extending rotor element **810**. However, the orientation of the axial gap generator assembly **702**" can be positioned elsewhere, for example, at an uphole end of the rotor **506***c*, or at an intermediate location of the rotor **506***c* between the uphole end and the downhole end, such as adjacent to a rotor element extending radially outward at an intermediate location of the rotor **506***c*. The second stator assembly **704***b*" is similar to the second stator assembly **704***b* of FIG. **8**A, except the second stator assembly **704***b*" includes a central aperture through which the rotor **506***c* extends through. The axial gap generator assembly **702**" can function like the axial gap generator assemblies **702**, and/or **702**' of FIGS. **8**A-**8**B in generating an amount of power, for example, for a magnetic bearing assembly.

In some implementations, the first stator assembly and second stator assembly can be partially incorporated with each other, for example, in that a stator back structure extends to either side of a rotor element positioned at a longitudinal end of the rotor or at an intermediate location along a length of the rotor, and/or can use a permanent magnet for a magnetic field source. For example, FIG. **8**D is a partial schematic cross-sectional side view of an example axial gap generator assembly **702**''' positioned adjacent to the rotor **506***c*. The axial gap generator assembly **702**''' is similar to the axial gap generator **702**" of FIG. **8**C, except the second stator back structure **712***b*''' of the second stator assembly **704**''' is formed as part of the first stator back structure **712***a*, and extends around the rotor element to position the second stator coils **716***b* on the opposite side of the radially extending rotor element, and the assembly **702**''' uses a permanent magnet **719** as opposed to electromagnetic coils **718***a*. The stator back structures together form a U-shape to substantially surround the rotor element **810** and position the stator coils adjacent to the rotor poles **717** of the rotor element **810**. The axial gap generator assembly **702**''' can function like the axial gap generator assemblies **702**, **702**' and/or **702**" of FIGS. **8**A-**8**C in generating an amount of power, for example, to for a magnetic bearing assembly.

While FIGS. **8**A-**8**D show various orientations of an axial gap generator assembly and respective positions of the stator assemblies, other orientations and positions of the stator assemblies are possible.

In either of the example axial gap generator assembly arrangements of FIGS. **8**A to **8**D, resultant forces applied to the rotor **506***c* based on the power output(s) from the generator assemblies may not restore the rotor back to centered position, but instead the rotor **506***c* reaches an equilibrium position where the thrust bearing force as a result of rotor displacement is equal to the force applied on the rotor. This applied force can be due to a variety of factors during operation, for example, from a compressor, pump, turbine, gravity, weight, or other imparted axial loads.

Referring to any of FIGS. **7**-**8**D, as the rotor **506***c* moves axially, the voltage of one stator assembly decreases while the voltage of the other stator assembly increases, changing the output current of the axial gap generator assembly (**702**, **702**', **702**", or **702**''') to the respective coil or coils of the respective thrust bearing assembly. This change in the output current can occur at a rate that is linearly responsive or non-linearly responsive to the axial position of the rotor **506***c*, where the change is greater than a negative stiffness of the thrust bearing assembly. For example, for an axial displacement of the rotor **506***c* of 0.001 inches, an axial force on the rotor **506***c* may be 10 lbs, but at an axial displacement of 0.002 inches, an axial force on the rotor **506***c* may be 20 lbs, 30 lbs, or a different non-linear response. As the rotor **506***c* axial displaces or deflects, a bearing force is increased to compensate for the deflection to arrive at a new equilibrium position of the rotor **506***c*.

In some implementations, the axial gap generator assembly (**702**, **702**', **702**", or **702**''') can utilize passive or active axial rotor damping. For example, axial rotor damping can be applied in the form of an eddy current damper. The eddy current damper can use copper and a magnetic field, or an axial damper can be an amplified version that uses a coil to sense magnetic field change and amplify this to be fed to the damping coils.

In some implementations of the axial gap generator assembly (**702**, **702**', **702**", or **702**'''), the second stator assembly is excluded, and the first stator assembly **704***a* generates the entirety of the amount of power supplied to a control coil of the thrust bearing assembly (e.g., the control coil **546** of the thrust bearing assembly **518**, or first coil **804***a* of thrust bearing assembly **802**). For example, while FIGS. **8**A through **8**D show two stator assemblies, an axial gap assembly may include only one stator assembly that provides an amount of power to a magnetic bearing, for example, to provide a constant bias axial force against a rotor using the amount of power from the one stator assembly.

While FIGS. **7**, **8**A, and **8**B shows the first stator assembly **704***a* and second stator assembly **704***b* as positioned at longitudinal ends of the rotor **506***c*, the stator assemblies can be positioned adjacent to a longitudinal side surface of the rotor, for example, such as a longitudinal side surface of a disc-like protrusion or rotor pole extending radially from the rotor **506***c*, for example, as shown in FIGS. **8**C and/or **8**D. During operation of a tool (e.g., thrust bearing module **504**) that rotates the rotor **506***c*, the axial gap generator assembly **702**, **702**', **702**", and/or **702**''' generates an amount of power as the rotor **506***c* rotates about the longitudinal axis A-A, where the amount of power generated by each stator assembly is affected by an axial position of the rotor **506***c* and/or a displacement of the rotor **506***c* along the longitudinal axis A-A, for example, in response to fluctuations in an environment surrounding the thrust bearing module **504**, fluctuations in an operation of the thrust bearing module **504**, and/or other factors.

In some implementations, a rectifier (not shown) is connected between the axial gap generator assembly and the thrust bearing actuator, for example, to convert the amount of power from an alternating current output (e.g., from the axial gap generator assembly) to a direct current output (e.g., received by the thrust bearing actuator). For example, a first rectifier (not shown) connected between the first stator assembly **704***a* and the first coil of the thrust bearing actuator can convert the first amount of power from the first stator assembly **704***a* from an alternating current output to a direct current output. Similarly, a second rectifier (not shown) connected between the second stator assembly **704***b* and the second coil of the thrust bearing actuator can convert the second amount of power from the second stator assembly **704***b* from an alternating current output to a direct current output.

In some implementations, an amplifier (not shown) is connected between the axial gap generator assembly and the thrust bearing actuator, for example, to amplify the output from the axial gap generator assembly to the thrust bearing actuator. For example, a first amplifier (not shown) connected between the first stator assembly **704***a* and the first coil of the thrust bearing actuator can amplify the first amount of power from the first stator assembly **704***a* to the first coil. Similarly, a second amplifier (not shown) connected between the second stator assembly **704***b* and the second coil of the thrust bearing actuator can amplify the second amount of power from the second stator assembly **704***b* to the second coil.

The axial gap generator assembly **702** is illustrated in FIGS. **7** and **8**A as incorporated into the thrust bearing module **504**. However, the axial gap generator assembly **702**, and/or the axial gap generator assembly **702'**, can be incorporated into other devices and tools with a rotating rotor. For example, the axial gap generator **702**, **702'**, **702"**, or **702'"** can be incorporated into a motor, generator, compressor, blower, pump, turbine, a combination of these, or another device. While FIGS. **7**, **8**A, **8**B, **8**C, and **8**D show one or two generator assemblies with one or two magnetic bearing assemblies, a different number of generator assemblies and/or magnetic bearings can be utilized. For example, multiple generator assemblies with multiple magnetic bearings assemblies (e.g., thrust bearings) can be incorporated on a single shaft (e.g., rotor) or on multiple shafts. For example, a downhole-type tool with a single shaft can incorporate one, two, three, or more axial gap generator assemblies and one, two, three, or more thrust bearings on a single shaft of the downhole-type tool.

The components described previously within this disclosure can be used to implement the example method **900** shown in FIG. **9**A. For example, method **900** can be performed by the example measurement tool **200**, **300**, **400**, **410**, **420**, **508**, **510**, and/or **512**. At **902**, a rotor is rotated about a longitudinal axis. At **904**, a stator assembly of an axial gap generator positioned adjacent to the rotor generates a voltage signal as a function of a gap spacing between the stator assembly and the rotor, where the gap spacing is parallel to the longitudinal axis, and the stator assembly is mounted to a movable support structure. At **906**, the movable support structure moves the stator assembly parallel to the longitudinal axis based at least in part on a physical property of an environment about the movable support structure.

The components described previously within this disclosure can be used to implement the example method **910** shown in FIG. **9**B. For example, method **910** can be performed by the example measurement tool **200**, **300**, **400**, **410**, **420**, **508**, **510**, and/or **512**. At **912**, a rotor is rotated about a longitudinal axis. At **914**, a first stator assembly of a first axial gap generator positioned adjacent to the rotor generates a first voltage signal as a function of a first gap spacing between the first stator assembly and the rotor, the first gap spacing being parallel to the longitudinal axis, where the first stator assembly is mounted to a diaphragm. At **916**, the diaphragm moves the first stator assembly parallel to the longitudinal axis based on a pressure of an environment about the diaphragm. At **918**, a second stator assembly of a second axial gap generator positioned adjacent to the rotor generates a second voltage signal as a function of a second gap spacing between the second stator assembly and the rotor, the second gap spacing being parallel to the longitudinal axis, where the second stator assembly is mounted to a temperature responsive material. At **920**, the temperature responsive material moves the second stator assembly parallel to the longitudinal axis based on a temperature of the environment about the temperature responsive material.

The components described previously within this disclosure can be used to implement the example method **1000** shown in FIG. **10**. For example, method **1000** can be performed by the example measurement tool **200**, **300**, **400**, **410**, **420**, **508**, **510**, and/or **512**. At **1002**, a rotor of a device is rotated about a longitudinal axis and within a housing of the device. At **1004**, a stator assembly of an axial gap generator positioned adjacent to the rotor assembly of an axial gap generator generates a voltage signal as a function of a gap spacing between the stator assembly and the rotor assembly, the gap spacing being parallel to the longitudinal axis. At **1006**, the stator assembly varies the voltage signal based on the gap spacing in response to a displacement of the rotor relative to the stator assembly.

The components described previously within this disclosure can be used to implement the example method **1100** shown in FIG. **11**. For example, method **1100** can be performed by the example axial gap generator assembly **702** of FIGS. **7** and **8**A, the example axial gap generator assembly **702'** of FIG. **8**B, the example axial gap generator assembly **702"** of FIG. **8**C, or the example axial gap generator assembly **702'"** of FIG. **8**D. At **1102**, a rotor is rotated about a longitudinal axis. At **1104**, a stator assembly of an axial gap generator positioned adjacent to the rotor generates an amount of power as a function of a gap spacing between the stator assembly and the rotor, the gap spacing being parallel to the longitudinal axis. At **1106**, the axial gap generator supplies the amount of power to a control coil of a magnetic bearing actuator.

A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made. Accordingly, other implementations are within the scope of the following claims.

What is claimed is:

1. A tool, comprising:

a device comprising a housing and a rotor, the rotor configured to rotate about a longitudinal axis; and

an axial gap generator comprising a stator assembly positioned adjacent to the rotor, the axial gap generator configured to generate a voltage signal as a function of a gap spacing between the stator assembly and the rotor and parallel to the longitudinal axis;

where the stator assembly comprises a first stator portion adjacent a first longitudinal side of the rotor, the gap spacing being a first gap spacing, and a second stator portion adjacent a second longitudinal side of the rotor opposite the first longitudinal side of the rotor, the second stator portion extends from the first stator portion radially outward and around an end of the rotor between the first longitudinal side and the second longitudinal side of the rotor, the axial gap generator configured to generate the voltage signal as a function of the first gap spacing between the first stator portion and the first longitudinal side of the rotor and a second gap spacing between the second stator portion and the second longitudinal side of the rotor.

2. The tool of claim **1**, where the device is a downhole-type device configured to operate in a downhole wellbore environment.

3. The tool of claim **1**, where the device comprises at least one of a motor, a compressor, a blower, a pump, or a thrust bearing.

4. The tool of claim **1**, where the axial gap generator is configured to determine an axial position of the rotor as a function of the generated voltage signal.

5. The tool of claim **4**, where the axial gap generator is configured to determine axial position of the rotor for an active axial magnetic bearing system.

6. The tool of claim **1**, where the axial gap generator is configured to vary the voltage signal based on a variance in the gap spacing in response to a displacement of the rotor relative to the stator assembly and parallel to the longitudinal axis.

7. The tool of claim **1**, where the axial gap generator comprises a permanent magnet to generate a magnetic field through the axial gap generator.

8. The tool of claim **1**, where the axial gap generator comprises an energized field coil to generate a magnetic field through the axial gap generator.

9. The tool of claim **1**, where the axial gap generator is positioned adjacent to a longitudinal end of the rotor.

10. The tool of claim **1**, where the voltage signal is the back electromotive force of the axial gap generator.

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